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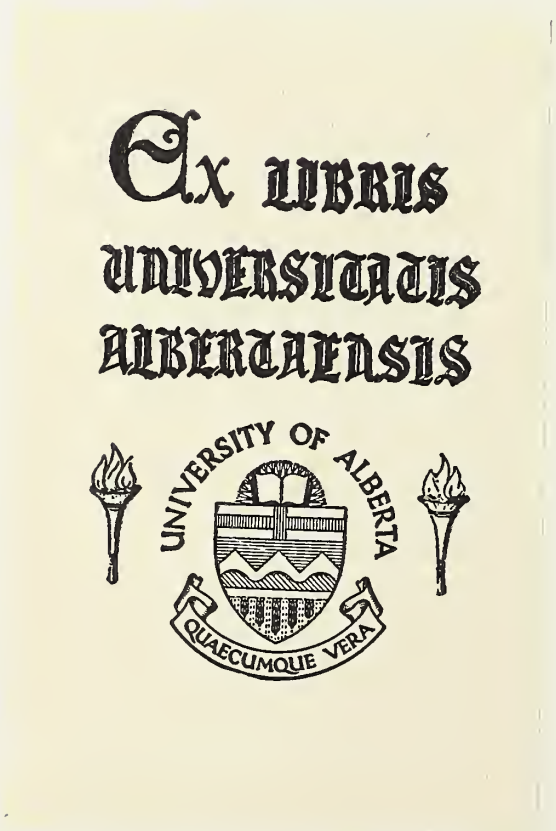

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THE UNIVERSITY OF ALBERTA

A SOIL FERTILITY STUDY ON THE WANHAM CLEARING AND BREAKING PROJECT

by

G. R. STERLING

A THESIS

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ABSTRACT

Experimental field trials on three farms in the Wanham and Silver Valley areas compared barley yields from rotations with and without fertilizers, the effect of rotations and fertilizers on soil nutrients, and the dollar returns for the years 1958 - 1965 inclusive. The two rotations were legume, legume-fallow, barley, barley (LLBB), and barley, barley, fallow (BBF). The NP fertilizer treatment on each rotation was 50 pounds of 33.5-0-0 plus 50 pounds of 11-48-0 per acre on the barley, and the 11-48-0 was increased to 100 pounds when the hay was fertilized. The P fertilizer treatment was 50 pounds of 11-48-0 on the cereal and 100 pounds on the hay. Soil samples were taken to a depth of 24 inches in the fall of 1965. The pH, conductivity, mechanical analysis, total nitrogen, available nitrogen, available phosphorus, and available potassium, were determined in order to observe any changes in the soils as the result of the rotations or fertilizers. The economic returns from the rotations and fertilizer treatments were studied.

Both the P and NP fertilizer treatments gave significant barley yield increases, but showed no response on the hay. The increases of grain yield credited to the fertilizers were about equal for the crops after legume fallow and after fallow.

The LLBB rotation produced almost as much barley per acre per year as the BBF rotation, and the legume one produced about one-half ton of hay per acre per year as well. The mean yields of barley for LLBB and BBF were 38.7 and 37.3 bu./ac. respectively. This difference was not significant.

The total nitrogen, available nitrogen, available phosphorus, and available potassium levels of the soils were not materially changed by the rotations or fertilizers, according to the analyses done in the Soil Testing Laboratory.

The P and NP fertilizer treatments very often returned a profit on

the BBF rotation. The NP fertilizer treatment returned a profit on the Wade and Fox Farms when both the hay and barley crops were fertilized. Profits were obtained on all farms when only the barley crops were fertilized with the NP treatment. The LLBB rotation with the NP fertilizer treatment applied on the barley crops returned $3.63 per acre per year more than the BBF rotation without fertilizers. At fertilizer costs and crop prices other than those assumed in this study, dollar returns would have been different, but not radically so in the opinion of the author.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
Soil Fertility Losses or Deficiencies	3
Rotations and Fertilizers	5
The Effect of Rotations on Physical Soil Properties	11
The Effects of Rotations and Fertilizers on Soil Nutrients	12
Economics of Rotations and Fertilizers	16
MATERIALS AND METHODS	18
The Area	18
The Soil Profiles	19
Fertilizers and Rotations	26
Fertilizers Applied	26
Cultivation Methods	28
Harvesting Methods	30
Soil Sampling and Analyses	30
Economic Studies	35
RESULTS AND DISCUSSION	38
Barley and Hay Yields	38
Soil Analyses	48
Mechanical Analysis	49
Soil Reaction (pH)	49
Conductivity	49
Available Nitrate Nitrogen	50
Available Phosphorus	54
Available Potassium	55

RESULTS AND DISCUSSION - Cont'd. Page

Total Nitrogen 61

Relationship of Crop Yields to Soil Analyses 62

The Dollar Returns 62

SUMMARY AND CONCLUSIONS 71

REFERENCES 73

APPENDIX I 76

APPENDIX II 78

APPENDIX III ..... In Pocket

LIST OF TABLES

Page

Table 1 - Losses of Nitrogen from a Cultivated Soil 14

Table II - Dry Matter and Nitrogen in Tops and Roots of Sweet Clover at time of Plowing Under 15

Table III - Rotation Sequence, Green and Fox Farms 27

Table IV - Rotation Sequence, The Wade Farm 28

Table V - Layout of Fields and Fertilizer Plots, Green and Fox Farms 29

Table VI - Layout of Fields and Fertilizer Plots, The Wade Farm 29

Table VII - Bushels of Barley and Tons of Hay Per Acre, The Green Farm 39

Table VIII - Bushels of Barley and Tons of Hay Per Acre, The Fox Farm 40

Table IX - Bushels of Barley and Tons of Hay Per Acre, The Wade Farm 41

Table X - Barley Yields in Bus./Ac. by Fields and Hay in Tons/Ac., The Green Farm 43

Table XI - Barley Yields in Bus./Ac. by Fields and Hay in Tons/Ac., The Fox Farm 44

Table XII - Barley Yields in Bus./Ac. by Fields and Hay in Tons/Ac., The Wade Farm 45

Table XIII - Barley and Hay Per Acre Per Year, The Green, Fox, and Wade Farms 46

Table XIV - Yields of Barley for the Rotations, Bushels Per Acre 47

Table XV - Mean Grain Yields for Selected Years for the Three Farms 47

Table XVI - Mean Yields for Fertilizers for the Three Farms 48

Table XVII - Rotation and Fertilizer Treatment Relationship 49

Table XVIII - Percentages of Sand, Silt and Clay 50

Table XIX - Soil Reaction (pH) 51

Table XX - Conductivity - mmhos per square cm 52

Table XXI - Available Nitrate Nitrogen 53

LIST OF TABLES - Cont'd.

	Page
Table XXII - Available Phosphorus	56
Table XXIII - Available Potassium	57
Table XXIV - Per Cent Nitrogen in the Soils	58
Table XXV - Available Nitrogen	59
Table XXVI - Available Phosphorus	59
Table XXVII - Available Potassium	60
Table XXVIII - Per Cent Nitrogen	60
Table XXIX - Barley Yield Summary	63
Table XXX - A Comparison of the Marginal Returns from the Rotations and Fertilizer Treatments, The Green Farm	64
Table XXXI - A Comparison of the Marginal Returns from the Rotations and Fertilizer Treatments, The Fox Farm	66
Table XXXII - A Comparison of the Marginal Returns from the Rotations and Fertilizer Treatments, The Wade Farm	67
Table XXXIII - Pooled Data Comparing V M P and M C for the Green, Fox and Wade Farms	69

INTRODUCTION

The Wanham Project was initiated by the Alberta Government to clear and break lands in the northern part of the province for the reestablishment of Alberta war veterans as farmers. The project was started in 1945 by Mr. O. B. Lassiter under contract with the Department of Lands and Forests, Government of Alberta. He agreed to break 200,000 acres at $25.00 per acre in five blocks of land, four in the Wanham - Tangent area, and one in the Silver Valley area. The land was broken in half section units containing not less than 240 cultivated acres and not more than 300. Two hundred and twenty-five such units were broken and veterans were established on them. At the outset, the veteran was to pay a one-third crop share for seven years, after which he could obtain title. In 1950, this was changed to a one-quarter crop share for a ten year period. During 1956, all of the units were appraised and the veterans were allowed to purchase the land at the appraised value less the amount of any crop share paid between 1945 and 1956. Considerable consolidation took place after the purchase agreement was brought into being, and consequently, by 1965, 125 veterans were farming the 225 units.

My first interest in the Wanham Project developed during 1945 and 1946, at which time there was considerable publicity regarding the Wanham, or as it was often called, the Lassiter Clearing Project in Northern Alberta. A group of six veterans, myself among them, travelled from Lacombe to this area with a view to settling on one of the projects. None of the six was prepared to attempt establishment on a unit. In the fall of 1948, the writer together with Lassiter employees walked over many of the units in an attempt to determine which areas were too heavily bush covered for reasonable clearing.

From 1945 to 1948, I was also involved with fertilizer improvement on Grey Wooded soils from the standpoint of a District Agriculturist serving

the Sundre, Rocky Mountain House, Rimbey, and Bluffton areas of Alberta, and became interested in the fertilizer plots at Breton established by the Soils Department of the University of Alberta. In 1929, Dr. F. A. Wyatt of that Department suggested that some legume crops in rotation would be absolutely necessary if satisfactory crop yields were to be obtained on Alberta Grey Wooded soils. In 1932, the following excerpt from a publication of that date confirmed his 1929 suggestion: "From these experiments it seems possible that the use of legumes and fertilizers will develop the production power of the poor areas of the wooded soils." His 1932 paper suggested that plowing down legumes as green manure was several times more effective than non-legume rotations.

The veterans on the Wanham Project experienced difficulty from the outset, and in 1950 I was one of a committee of three established by the Alberta Government to assist with the collection of bad accounts on the Wanham Project. This committee interviewed each veteran several times, and attempted to advise the veterans on farming procedures which would give them sufficient revenue to meet their obligations.

In 1956, the Alberta Government passed The Land and Forest Utilization Act, which established a Committee with the author as Chairman to work on the proper utilization of lands throughout the Province of Alberta. The Veterans' Association at Wanham requested that experimental rotation and fertilizer plots be established on some of the land in the Wanham Project in an effort to determine better farming procedures. The Committee complied with this request late in 1957, and established experimental plots early in the spring of 1958. This thesis reports the results of experiments carried on over the eight year period, 1958 to 1965 inclusive.

REVIEW OF LITERATURE

The literature studied prior to starting and during the experiments appeared to fall into five general headings, and these will be used in presenting this review. They are as follows:

(1) Soil Fertility Losses or Deficiencies.

(2) Rotations and Fertilizers to Increase or Maintain Grain Yields.

(3) The Effect of Rotations on Physical Soil Properties.

(4) The Effect of Rotations and Fertilizers on Soil Nutrients.

(5) The Economics Involved with Rotations and Fertilizers.

Soil Fertility Losses or Deficiencies:

Lehane et al. (1964) reported on growing wheat in tanks which were 15" in diameter and 5' deep, for a 36-year period. Their rotations were continuous wheat with rainfall only, and with added water, and a 2-year rotation of wheat and summer fallow with rainfall only, and with added water. This work showed that at the end of the 36-year period, there were no marked differences in the organic carbon and nitrogen content or the pH of the different rotations. They noted that phosphorus was being removed by crops down to a depth of five feet, particularly when moisture conditions were adequate. Both rotations revealed that nitrogen and phosphorus deficiencies occurred in a relatively short time.

Hill (1954) reported on wheat yields and soil fertility as determined at Lethbridge, Indian Head, and Brandon Experimental Stations. Grain rotations at each station had been conducted for approximately 40 years. He reported that a consistent decrease in the percentage of nitrogen had occurred since 1910. He noted that the smallest loss occurred in the 10-year rotation including 3 years of alfalfa at Lethbridge, and the highest loss was in a 9-year

rotation including 3 years of summer fallow. He contended that a cropping practice including wheat and summer fallow can be continued profitably for some time in Western Canada if soil erosion and weeds can be controlled.

Walker and Bentley (1961) studied sulphur deficiencies. The 157 locations represented 18 soil series in west central Alberta. They rated the sulphur deficiency of the soil by determining the extractable sulphur of the plants growing thereon. They concluded that yield responses of alfalfa, alsike clover, and red clover, to sulphur fertilizer were not confined to specific soil series or geographical areas. Their data revealed that extractable sulphur and extractable sulphate remained at low levels in alsike clover and alfalfa plants grown on land where the soil supply of that element was inadequate.

Newton et al. (1945) studied the effects of cultivation and cropping systems (mainly the commonly practised grain and fallow system) on the chemical composition of prairie province soils, by comparing the composition of virgin and adjacent cultivated soils. Samples, to a 6-inch and in some cases a 12-inch depth, were taken from both virgin and cultivated soils at 85 locations in Alberta, Saskatchewan and Manitoba. The total nitrogen and organic carbon losses in the virgin soils compared to cultivated ones were variable. At some locattions the losses were as great as approximately 50% of the original organic carbon and 40% of the nitrogen, whereas in other cases there was no apparent loss. The losses of original nitrogen from the surface 6 inches of the Brown, Dark Brown, and Black soils were much alike and were about 18% of the original content. The losses of nitrogen was higher on the Grey Wooded soils. They found that soils in a legume-grain rotation did not lose as much organic matter or nitrogen as soils in a grain-fallow rotation. The Dark Brown and Grey

Wooded soils which were cultivated lost significant amounts of phosphorus as reported by Brown et al. (1942).

Rotations and Fertilizers:

Toogood et al. (1962) reporting on research at Breton, Alberta, for the period 1930 - 1961, showed that a rotation including legumes and grasses produced more satisfactory grain yields than a continuous wheat or a wheat-fallow rotation. The grain and forage crops were complementary, and the best fertilizer in conjunction with legumes increased the wheat yields by 172%, the oats following wheat by 91%, and the barley following the oats by 128%. The wheat-fallow plots receiving no fertilizer produced over the period an average of 7.6 bushels per acre per year, while the legume and grain rotation plots produced 13.7 bushels per acre per year. The wheat yields of the legume rotation in conjunction with some of the better fertilizers varied from 30 to 34 bushels. At the same time the rotation produced a crop of either oats, barley, wheat, or legumes, every year. The hay yield was approximately 2.5 tons per acre annually. Other data showed that the fertilizers, which produced high yields, also improved the feed value of the hay.

Carder and Hanson (1951) reported on a legume and cereal rotation started at Beaverlodge, Alberta, in 1934 as compared to a grain and fallow one. Rotation 1 was sweet clover seeded, sweet clover, wheat, wheat. Rotation 2 was oats and sweet clover, sweet clover, wheat, wheat. Rotation 3 was oats, fallow, wheat, wheat. Several combinations of fertilizers including manure were superimposed on the 3 rotations. They concluded that two rounds of the rotation gave insufficient information for the determination of residual effects, and an inadequate sample of the climatic variation. Results indicated that sweet clover may substitute for summer fallow. However, the yields of the two wheat crops following sweet clover, seeded without a nurse crop, were not

significantly different from the yields after fallow. He noted that no appreciable yield benefits were obtained when the sweet clover was handled as a green manure as compared to plowing the sweet clover stubble after hay. He concluded that the robust root system of sweet clover was more important than the top growth from a soil fertility standpoint.

The Brandon Experimental Station, Manitoba, (Progress Report 1953-1957) had four rotations continuously in operation since 1911. These were:

Rotation D - manured summer fallow, wheat, wheat, oats

Rotation E - summer fallow, wheat, wheat, oats

Rotation G - corn (manured), corn, wheat, hay, hay and break, wheat,oats

Rotation H - manured summer fallow, wheat, hay, hay and break, wheat, oats

The two wheat crops in Rotation G produced a slightly higher yield per acre per year than the 2 crops of wheat following summer fallow (Rotation E). The 1958-1961 Research Report from the Dominion Experimental Farm, Brandon, stated that sweet clover when used as a green manure crop over a long period of years tended to increase crop yields.

The 1958-1961 Research Report, Dominion Experimental Farm, Beaverlodge, Alberta, reported that, on a Dark Grey soil, 12 years of continuous wheat cropping produced more wheat than a fallow, wheat, wheat rotation or a sweet clover, wheat, wheat rotation. However, the continuous cropping favoured weeds and impaired soil structure.

Rotations involving the use of grasses and legumes met with little success at Scott, Saskatchewan, (Progress Report 1937-1947). This was due to the dry conditions of the area.

The 1949-1958 Progress Report from Fort Vermilion indicated that a 6-year rotation including forage crops was started in 1947. The average annual

return of 25 bushels per acre was slightly higher than the average return for the area. Their soils were low in nitrogen and organic matter and they recommended a legume-grass rotation to build up the fibre.

Poyser et al. (1957) reported on a fertility experiment initiated in 1919 at the University of Manitoba. He compared two rotations:

Rotation 1 - fallow with a green manure crop, wheat, corn, wheat

Rotation 2 - fallow, wheat, corn, wheat

A mixture of sweet clover and red clover, plowed down when in full bloom was used as the green manure crop. There was little yield response to the green manure in the first year after fallow, however, near the end of the period a yield increase occurred in the second and third crops after legume-fallow. They suggested that the increased response to legume-fallow probably reflected a decline in the ability of the soil to supply nitrogen as total nitrogen declined.

Carlson et al. (1963) reporting from Mandan, North Dakota, on legume and non-legume rotations under irrigation, found that nitrogen produced responses to all crops in the non-legume rotations, and that phosphorus alone decreased the yield of corn forage. With adequate nitrogen in the rotation however, phosphorus increased the yields of barley, corn and potatoes. In the legume rotation alfalfa increased the supply of available nitrogen. The yields of barley and corn were higher in the legume rotation than in the non-legume rotation regardless of the fertilizer treatment. He concluded that the higher yields in the legume rotation resulted mainly from the available nitrogen contributed by the alfalfa.

Russell (1917) reporting on Agdell Field at Rothamsted compared a rotation of swedes, barley, clover, and wheat, to one of swedes, barley, summer fallow, wheat. Over a long period of time, the wheat following the

clover yielded 8.2% less than the wheat following summer fallow. However, in the case of the rotation a crop was grown every year, while in the summer fallow rotation only three crops were grown every four years. The better mineral fertilizers, however, gave an increase for wheat after legume crops in the amount of 17.6% compared to the wheat following fallow. Broadbalk Field at Rothamsted grew wheat continuously for almost 100 years. The average wheat yield for the first 60 years (1852-1912) was 12.6 bushels. During the ten years (1903-1912) the yield was reduced to ten bushels per acre per year, which indicated a slight decline in fertility. The manured plots and the best chemical-fertilized plots yielded 35.2 bushels and 36.0 bushels respectively per acre per year for the same 60 years. There was little or no decline in the wheat yields of the plots receiving the better fertilizers or manure. Nitrogen determinations of the soil showed that nitrogen content, of the continuous wheat without fertilizer plots,declined over the 60 year period. It fell to a more or less stabilized level and then remained at or near this level.

Snider (1950) reported on the yields from the Morrow plots, Urbana, Illinois. These plots laid out in 1876, were cropped as follows:

(1) corn, oats, clover

(2) corn, oats

(3) continuous corn

On the Morrow plots red clover in the rotation resulted in higher yields of corn and oats and also increased the protein in the corn and oat grain. At the same time, the organic matter and nitrogen in the soil were maintained at a considerably higher level than when legumes were not grown. Snider quoted the 1943 yields as 24 bushels higher for the corn after clover, as compared to the corn-oats rotation. When manure, limestone and phosphate were added, the yields of corn were 101 bushels for the clover rotation compared to 85 bushels

in the corn-oats rotation.

Friesen*(1965) at Lacombe, Alberta, reported on Rotations "O", "K", and "C", which were as follows:

Rotation O - potatoes, wheat, oats, fallow, wheat, hay, hay and break

Rotation K - corn, wheat, barley, hay, hay, hay and break

Rotation C - fallow, wheat, wheat

The long term average wheat yield per crop year on Rotation K, which had an equal proportion of cereals to hay, was 23.5 cwt./ac. compared to the second year wheat yield of 22.9 cwt./ac., and the fifth year wheat yield of 20.1 cwt./ac. in Rotation O. The average yield per crop year of wheat after fallow and wheat after wheat in Rotation C was 15 cwt./ac. and 9 cwt./ac. respectively. Wild oats were a problem in Rotation C, but not in O or K. In 1948, part of Rotation C was changed to fallow, barley, barley, in an effort to control the wild oats. The average barley yield per crop year after fallow and barley was 19.2 cwt./ac. and 15.6 cwt./ac. respectively, compared to the barley yield of 20.5 cwt./ac. in Rotation K. Small plot crop rotations were established by Friesen at Lacombe in 1955. Eight year averages indicated that continuous barley gave a yield of 15.9 cwt./ac. and the first and second years of the rotation barley, barley, fallow, yielded 37.2 cwt./ac. and 27.5 cwt./ac. respectively. The barley yields in a rotation of barley, hay, hay and break, barley, oats, fallow, were 36.2 cwt./ac., and 34.2 cwt./ac. Again wild oats were a real problem in the continuous barley, but no problem in the other rotations.

The North Eastern Alberta Agricultural Service Board Association in meeting on February 17, 1964, requested the Research Branch, Canada Department of Agriculture, Lacombe, to investigate the poor barley yields of North Eastern Alberta. In the spring of 1964, McBeath*(1965) established experiments which

* Private communication

included nitrogen, phosphorus, and potassium, in a factorial design with four replicates on Grey Wooded soils near St. Lina and Myrnam. The rates of fertilizers were ammonium nitrate (35.5-0-0) at 200 lbs./ac., ammonium phosphate (11-48-0) at 100 lbs./ac., and muriate of potash (0-0-60) at 100 lbs./ac. singly and in all combinations of two fertilizers together, and all three fertilizers together. The yields at Myrnam for the single application of fertilizers were not significantly different from the check which was 25.1 bushels per acre. The combinations of any two and all three fertilizers gave significantly greater yields varying from 32 to 37.8 bushels. Similar results with significant increases, although not as large, were obtained at St. Lina.

In 1965, further experiments on Grey Wooded soils at three sites between Myrnam and St. Lina, Alberta, were established by McBeath with three levels of nitrogen, phosphate and potash. The rates were 0, 25, and 50 lbs./ac. of each nutrient, alone and in all possible combinations. The results indicated that the apparent fertilizer requirements at two sites were 50 lbs./ac. of nitrogen plus 25 lbs./ac. of phosphate. At the third site the requirement was 25 lbs./ac. nitrogen plus 25 lbs./ac. phosphate. McBeath concluded that soil fertility was low in this Grey Wooded soil area. He recommended adequate amounts of fertilizers, the utilization of all farm manure, and the use of soil-improving legume crops.

Drover (1956) reported on the following rotations in Australia:

(1) continuous wheat

(2) fallow, wheat

(3) fallow, wheat, voluntary pasture

(4) fallow, wheat, lupins, lupins

The rotation involving the lupins was the only one of the four which maintained

soil nitrogen in the levels approaching those of the virgin soil nearby. By contrast the other rotations had serious losses in both carbon and nitrogen.

Allaway (1957) reported on cropping systems used in the United States. He stressed that many crops have a beneficial effect on succeeding ones. He emphasized the benefits of legume grain rotations and also mentioned the benefits of tree or forest fallow as practiced in many tropical countries. He reported an experiment on Paulding clay soil in Northern Ohio where rotations of alfalfa, brome grass, and corn, were compared with continuous corn. He noted that during wet seasons it was often possible to plow and cultivate the soils of the alfalfa brome grass rotations, while excess water was still standing on the continuous corn rotations.

Siemens (1963) stated that crop rotations are more complex, require a long time to complete, and are more subject to misinterpretation than other subjects of agricultural investigation. To him it seemed reasonable that a number of additional resources should be utilized for long term comparisons between the 3-year, 6-year, and 8-year types of rotations. He thought that the only practical cropping program is one with built-in flexibility, which allows for changing market conditions. He pointed out that 50-year comparisons between 2, 4, and 8-year rotations are of little value to the farmer who must shift his production pattern to keep in step with market demands.

The Effect of Rotations on Physical Soil Properties:

Toogood and Lynch (1959) reported on the mean weight diameter of soil aggregates of the Breton plots. Two inch soil cores to a depth of 6 inches were taken from each of 55 plots, and the diameter of soil aggregates determined by the wet sieving procedure. The aggregate analysis revealed marked differences between the two rotations, but few if any among the fertilizers. The average mean weight diameter of aggregates in soils in the 5-year legume-grain rotation was

almost double that for soils in the wheat-fallow sequence.

Fletcher and Livingston (1949) studied the physical improvement that legumes cause on an eroded soil. The area in question was stripped of the A horizon of about one foot by mechanical road machinery. After 8-years' growth of Lespedeza sericea, the upper several inches of soil which was artificially eroded, changed as follows:

(1) Total porosity was increased.

(2) The volume of non-capillary pores which drain at low tensions was enlarged.

(3) The water intake and the air flow in the surface soils was increased.

This work showed that the soil after producing legumes for eight years was much better physically than the original eroded sub-soil for the production of site-demanding species.

Friesen* (1965), beginning in 1959, measured the amount of water stable aggregates on Rotations "O", "K", and "C", which were described earlier. It was noted that the proportion of water stable aggregates increased a small but consistent amount under the hay crops in Rotations "O" and "K", but broke down rapidly when the sod was broken. The mean weight diameter of the aggregates was greater for "O" and "K", when they were producing hay than for Rotation "C". He studied the per cent organic matter in all fields of the three rotations. No significant differences within or between the various rotations occurred from 1960 to 1964.

The Effects of Rotations and Fertilizers on Soil Nutrients:

Toogood et al. (1962) reported on the effect that rotations and fertilizers have on pH, nitrogen, phosphorus, and potassium. Soil samples were taken from the various plots at Breton in June 1957, and pH, available and total nitrogen, available phosphorus, and available potassium determined. Statistical

* Private communication

analysis was not considered possible but generalizations regarding the soil analyses were as follows:

(1) There was a slight effect on pH. The higher yielding plots had a lower pH than the lower yielding plots. The pH in the legume rotation was lower than the wheat-fallow series.

(2) The nitrogen in the soil of the legume rotation appeared slightly higher than in the plots growing continuous wheat. Nitrates were usually higher in the legume rotation than in the continuous wheat.

(3) Phosphorus had apparently accumulated in the low yielding plots which had received phosphorus fertilizer.

(4) The plot treatments had little effect on available potassium.

(5) The study of the Breton soils showed that fertility in the plots of the wheat-fallow series had diminshed, while in the legume rotation series the fertility was actually improved.

Dubetz (1954) at the Lethbridge Experimental Farm reported on an irrigation rotation started there in 1911, and which included 6 years out of 10 in alfalfa. Soil samples were taken at the start and in 1922, 1940, and 1951. While the soil became more alkaline during the 40 years, no changes occurred in the phosphorus and potassium status. He reported significant increases in total nitrogen and organic matter. By 1951, the nitrogen had increased by 7 per cent and the organic matter by 10.5 per cent in the surface 6 inches compared to 1911. At the 6-inch to 12-inch depth, the increases were 42.5 and 45.2 per cent respectively.

Poyser et al. (1957) compared the levels of nitrogen and organic carbon of a legume rotation with a non-legume rotation at Winnipeg, Manitoba. He reported an average decrease of 27.9% for organic carbon and 15.9% for nitrogen

over a 25 year period. The levels of organic carbon and nitrogen were significantly higher in the legume fallow rotation compared to the fallow check.

Gosdin et al. (1949) reported on long term rotations, with and without legumes, grown on Southern Piedmont Experimental Station, Watkinsville, Georgia. Not only did the legume rotations return higher yields, but as the amount of legumes in the rotation increased, the amounts of organic matter and nitrogen in the soil became greater. The greatest gains were obtained in rotations of almost continuous hay.

Russell (1961) reported on the nitrogen content of the Broadbalk Field after 49 years of cropping (1865-1914). Figures in Table I indicate that the greatest loss in per cent of nitrogen occurred when no manure was applied. Farmyard manure and 86 lbs. of nitrogen when applied either increased the nitrogen supply or maintained it at a consistent level for the 49 years.

TABLE I - LOSSES OF NITROGEN FROM A CULTIVATED SOIL
Broadbalk, Rothamsted, 49 years, 1865-1914

Per Cent in Top 9 Inches of Soil

	Farmyard Manure (Plot 2B)	No Manure (Plot 3)	Complete Artificials (86 lb. N as sulphate of ammonia annually) (Plot 7)	Complete Artificials (86 lb. N as sulphate of ammonia annually) (Plot 13)[1]
N in soil in 1865, per cent	0.196	0.114	0.123	0.121
N in soil in 1914, per cent	0.236	0.092	0.120	0.122

1 Plots 7 and 13 are almost duplicates; same amounts of N in different fertilizers.

Russell (1961) reported on the organic matter content of arable soils

at the Ohio Experimental Station, Wooster. Crops had grown at this station since 1894 without manure or fertilizer. The nitrogen content was checked initially in 1894 and again after 30 years of continuous maize, 30 years of continuous wheat, 30 years of rotation of maize, oats, wheat, clover, timothy, and after a 30-year rotation of maize, wheat, and clover. Results showed that nitrogen dropped to 33% after the continuous maize, to 50% after the continuous wheat, to 75% after the 5-year rotation, and to about 82% after the 3-year rotation.

Snider (1950) reported on the dry matter and nitrogen content of tops and roots of sweet clover which were plowed down as a green manure crop at Urbana, Illinois. He showed that there was considerably more nitrogen and dry matter in the roots than in the tops of sweet clover. See Table II.

TABLE II - DRY MATTER AND NITROGEN IN TOPS AND ROOTS OF SWEET CLOVER AT TIME OF PLOWING UNDER*

Field and Sampling date	Depth of Roots	Part of Plant	Dry Matter	Nitrogen
			lb.	lb.
Spring Valley	Deep	Tops	290	17
April 5-20		Roots	3,770	176
		Total	4,060	193
DuBois	Shallow	Tops	1,490	52
April 25		Roots	1,080	27
		Total	2,570	79
Carthage, not cut in fall	Deep	Tops	960	46
April 13-18		Roots	1,740	83
		Total	2,700	129
Carthage, cut in early fall	Deep	Tops	340	16
		Roots	710	26
		Total	1,050	42

* Average of two years at Spring Valley and three years at Carthage; Dubois data are for one year only.

Economics of Rotations and Fertilizers:

Heady and Jensen (1951) reported on the economics of crop rotations and land use at Ames, Iowa. He stressed the fact that a farmer must use each unit of resource where it will bring in the greatest return. The farmer must place his input where he expects the greatest results. If forage crops are complementary to grain crops, then he should utilize them until they reach the competitive stage. Forage crops are only complementary to grain crops when an increased acreage production of these forage crops also increases the total production of grain from a given acreage. The forage itself need not be utilized if it is complementary to grain production. He pointed out that in the Morrow plot experiments in Illinois, the forage, corn, oats, clover rotation had a complementary effect on total grain production compared to continuous corn. The forage in the Ohio experiment (1937-1943) which consisted of corn, corn, corn, wheat, alfalfa, had complementary effects on total grain output compared to continuous corn. However, when the rotation corn, wheat, alfalfa, was compared with C-C-C-W-A the forage in the former rotation was competitive because the greater acreage in alfalfa reduced the total grain production. They used further illustrations to stress the fact that every farmer must consider all of his own circumstances before he can conclude that legume crop rotations are beneficial on his farm.

Heady (1957) reported further on the economics of cropping systems. He again pointed out that some crops are complementary to each other, for example - legumes and corn. Besides this physical complementarity, he stressed that one must also consider the economic factors of the whole farming operation. When this was done, crop competition usually came into play.

Toogood et al. (1962) reported on the Breton plots and stated that

the financial returns from the use of fertilizers varied from 65% to 253% in the wheat-fallow rotation, and from 334% to 1936% in the legume-grain rotation. Their report indicated that ammonium phosphate 16-20-0, or ammonomium sulfate 21-0-0 gave excellent investment returns, particularly when used with legume rotations. They suggested that the rate for 16-20-0 appeared to be from 50-70 lbs./ac. per year, drilled in with the grain crops, with possibly heavier rates broadcast on the forage crops.

The literature review indicates that the grain yields of a continuous grain rotation decrease with time. A rotation containing legumes on the other hand tends to maintain, or in the case of most Grey Wooded soils, to increase yields of grain. The grain yields per acre per year tend to be lower for a rotation containing one-half summer fallow than for most legume type rotations.

The soil nutrients, N, P, and K, decrease in soils when continuous grain is grown. They appear to reach a low level which is maintained for many years.

Evidence in the literature indicates that soil physical properties are improved by the use of rotations containing legumes.

The literature contains many instances where fertilizers gave significant yield increases on hays and grains. Favorable economic returns are reported for the application of fertilizers and for the use of legume rotations.

MATERIALS AND METHODS

Experiments, involving rotations in combination with fertilizers, were established in the fall of 1957 on the farms of R. G. Green, SH 20-79-3-W 6; Fox Brothers, WH 35-81-10-W 6; and R. Wade, WH 19-78-2-W 6. The first experimental crops were seeded in 1958. The previous cropping history of each of these relatively new farms included only cereal production and summer fallow. The first cereal crops were grown on the Green, Fox and Wade Farms in 1948, 1952, and 1949 respectively.

The Area:

The Wade and Green Farms lie within the Rycroft and Watino Soil Survey Sheets as mapped by the Research Council of Alberta and described in Report No. 15 by Odynsky and Newton (1950). The Fox Farm lies approximately 18 miles west and 6 miles north of the north west corner of this survey sheet. The Cherry Point Soil Survey Report, covering the Fox Farm area, has not yet been published. Report No. 15, describes in detail the parent materials of the soil, the vegetation, the development of the area, and the climate. These are reviewed in what follows.

The whole area consists mainly of remnants of till plain and a low lying laking basin. Wanham is in the main part of this basin. The elevation varies from 1,800 to 2,100 feet. The area was originally covered with poplar and coniferous trees, mainly spruce, but several fires not only denuded the cover but also burnt the surface organic matter. After the fires, poplar became established, much of which was also burnt during the late 20's. Remnants of the burnt over spruce, and small groves of poplar were evident when I traversed the area in 1948.

The railroad was built into McLennan in 1915 and extended through

this area to Spirit River in 1916. Most of the settlement was in the area of Spirit River, Rycroft, Dunvegan, and Wanham. The land near the Fox Farm was not settled until the late 40's.

Good climatological data are not available for the area. Two stations near the area reporting these data are Rycroft and Dunvegan. Dunvegan is in the river flat at an elevation of 700 feet, where the climate is entirely different from that of the surrounding upland plain. While Rycroft is in the area, the records from this station are for a very short term and are not reliable as a long term average for the area.

The Dunvegan station reported a long term average of 14.01 inches of rainfall, while Fairview, which is about 15 miles north east of Dunvegan, reported 19.67 inches. Settlers in the area claimed that rainfall at both Silver Valley and Wanham was somewhat less than that recorded at Dunvegan. Frost free growing seasons are as follows:

Beaverlodge	-	131 days
Dunvegan	-	107 "
Rycroft	-	108 "
Fairview	-	133 "

The Soil Profiles:

The Fox Farm, and immediate vicinity, was not covered by regular Alberta Soil Survey at the time the experiments were set up. However, S. W. Reeder and M. D. Scheelar, Research Council Soil Surveyors, upon special request made a soil survey of the plots on the Fox Farm. The topography is very gently undulating with the southern portion of the plots sloping slightly towards the south. This field has three soils all developed on Lacustro-till, and described by Reeder and Scheelar as follows:[1]

1 Reeder, S. W. and Scheelar, M. D. - Private Communication

"A - Donnelly - Solonetzic Grey Wooded

Moderately well drained, clay loam to clay.

These soils are found at the higher elevations of the microtopography of the plot area. The following is a description of a moderately well drained soil profile of the area:

Horizon	Depth in Inches	Description
Ap	4"	Dark greyish brown mixture of O, Ah, and Ae horizons; loam with little definite structure, friable.
Ae	2	Light yellowish brown very fine sandy loam, medium platy, friable.
BA	2	Dark yellowish brown clay loam to clay, medium nuciform to blocky, firm.
Bt1	6	Dark brown clay; medium blocky to massive; very firm; common faint mottles, fine to medium in size.
Bt2	12	Dark brown clay; medium blocky to massive; very firm; many distinct mottles, medium in size.
BC	8	Greyish brown to dark grey clay; massive; plastic; few faint mottles, small in size.
C	34^{+}	Dark grey clay; massive; plastic; common faint mottles, small in size; small stones are common.

B - Donnelly - Solonetzic Grey Wooded

Imperfectly drained, clay loam to clay.

These soils are found at the intermediate elevation of the micro-topography of the plot area. They are the predominant soils of the area taken up by the plots. The following is a description of the soil profile found in the plot area:

Horizon	Depth in Inches	Description
Ap	4	Dark grey brown mixture of O, Ah, and Ae horizons; loam with little definite structure; friable; many distinct mottles, medium in size.
Ae	2	Light yellowish brown very fine sandy loam; medium platy; friable; many distinct mottles, medium in size.
Bt	18	Dark brown clay; medium blocky to massive; very firm, many prominent mottles, medium in size.
BC	8	Greyish brown to dark grey clay; massive; plastic; common distinct mottles, medium in size.
C	32^{+}	Dark grey clay; massive, plastic; common faint mottles, fine to medium in size; small stones are common.

The Donnelly soils are rated as fairly good to good arable soils. These soils, in general, are relatively low in organic matter content and their sub-soils tend to have a restricting influence on the

penetration of water and of plant roots. Crop rotations that include deep-rooted crops tend to have the effect of opening up and improving the structure of these soils. Fertility experiments conducted on similar soils by the Beaverlodge Experimental Farm show indications of a marked response to applications of manure and phosphate fertilizers.

C - Snipe - Grey Wooded Gleysol

Poorly drained, clay loam to clay.

These soils are found at the lower elevations of the microtopography where drainage deficiencies are apparent on the plot area. The following is a description of the soil profile:

Horizon	Depth in Inches	Description
Ap	4	Dark grey brown mixture of O, Ah, and Ae horizons; loam with little definite structure; friable; many prominent mottles, medium to coarse in size.
Ae	3	Light yellowish brown very fine sandy loam; medium to coarse platy; friable; many prominent mottles, medium to coarse in size.
Bg	20	Dark grey clay; massive; plastic; many prominent mottles, medium to coarse in size.
G	24^{+}	Dark greyish clay; massive; plastic; few prominent mottles, small to medium in size. Small stones are common."

The Rycroft and Watino Survey Report No. 15 (Op. cit.) shows the soil

on the Green Farm as a Davis-Judah. While the Davis soil predominates, there is a mixture of the two soils in the plot area. The plot area is gently undulating with drainage to the north. The report describes the Davis soil as follows:

"There is little uniformity as regards the depth to the different strata or as regards the thickness of the respective strata. A solum that is predominantly silty is characteristic of these soils. Following is a generalized description of a typical Davis soil profile:

Horizon	Depth in Inches	Description
Ao	0 - 2	Dark brown organic debris. pH 7.2
A1	1 - 2	Brown loam to silt loam, often absent. pH 7.0
A2	2 - 5	Light brown to very pale brown very fine sandy loam to silt loam, platy, very friable. pH 6.4 to 6.8
A3	5 - 8	Pale brown silt loam to silty clay loam, vesicular, nuciform, friable. pH 6.2 to 6.6
B1	8 - 20	Yellowish brown silt loam to silty clay loam, weakly columnar, nuciform, friable. pH 5.4 to 5.8
B2	20 - 26	Brown to strong brown silty clay. Somewhat more compact than the B1 horizon. pH 5.6 to 6.0
Bca	26 - 30	Light brownish grey silty clay and light yellowish brown silt and very fine sand

		strata that often exceed 12 inches in thickness. Fairly high to high lime. pH 8.0 to 8.6
C	30 - 50	Light yellowish brown very fine sand to silt loam in upper 8 inches. Remainder very fine sand to silt with occasional thin bands of silty clay."

The Judah soil on the Green Farm will be described in connection with the Wade Farm.

The soil on the Wade Farm is predominately Judah. The plots are gently rolling to rolling with a rather large hill in the southern end of the plots, and another one approaching the northern end. Odynsky and Newton described this soil as follows:

"Judah soils can be recognized by the brown colored surface horizon and by a brown fairly heavy textured, usually stone-free subsoil. The structure of the solum is fairly loose and the structural aggregates lack the cohesion typical of Falher soils. Furthermore, there is often a gradual greying of the lower part of the A horizon rather than any distinct A2 horizon. With respect to their color and structure they are unlike other degraded black soils in this area and more closely resemble brown forest soils. The following is a generalized description of Judah soil profile:

Horizon	Depth in Inches	Description
Ao	0 - 1	Dark brown decomposed and semi-decomposed leaf litter. pH 7.3 to 7.6
A1	1 - 4	Dark brown to brown silt loam to silty

		clay loam, fine granular to crumb, friable. pH 6.9 to 7.2
A3	4 - 6	Yellowish brown very fine sandy loam to silt loam, fine granular to crumb, friable. pH 6.5 to 6.8
B1	6 - 12	Brown to dark yellowish brown silty clay loam to silty clay, granular to nuciform, friable. pH 5.8 to 6.2
B2	12 - 18	Similar to above but somewhat more compact. pH 5.6 to 6.2
B3	18 - 24	Dark yellowish brown silty clay loam to silty clay, nuciform, friable. Occasionally has light yellowish brown silty and very fine sandy laminae. pH 7.0 to 7.4
Bca	24 - 36	Brown to yellowish brown silty clay, nuciform, friable, frequently laminated, usually fairly high in lime. pH 8.1 to 8.3
C	36 -	Greyish brown silty clay loam to silty clay, granular to nuciform, friable. Brownish yellow laminae of very fine sand or silt are often present. pH 8.1"

The soil on each of the three farms is variable. The Green Farm has many small hills with well drained soil on the tops to poorly drained soil in the hollows. In the spring, it was often necessary to wait a few days for the hollows to dry enough for proper cultivation. The Wade Farm plots have two hills where the soil is well drained, and two slough-like areas where

drainage is poor. The Fox plots are almost level, but the lower areas are poorly drained. The fine texture of the soils and the low organic matter content made them difficult to cultivate. Fox Brothers reported that the legume rotation fields were easier to cultivate during 1964 and 1965 than the non-legume ones.

Fertilizers and Rotations:

The experimental plots on the Green and Fox Farms were 1,320 feet long and 660 feet wide. The area was divided into five fields of 132 feet by 1,320 feet. The rotation on Fields 1, 2, and 3, consisted of legume, legume and fallow, barley, barley. The rotation on Fields 4 and 5 was barley, barley, fallow. Table III shows the crop sequence followed in Fields 1 to 5 inclusive on the Green and Fox Farms for the years 1958 to 1965. The cereal crop was Olli barley, and the legume crop was Red Clover. In the spring of 1958, Fields 1 and 2 were seeded to legume, and Field 1 was plowed in 1959 in an effort to get into the rotation quickly.

The area on the Wade Farm was also 1,320 feet by 660 feet. The 660 feet width was divided into four fields because Sweet Clover was used as the legume crop and only produced one hay crop per sequence. The rotation on Fields 1 and 2 was Sweet Clover-fallow, barley, barley, and on Fields 3 and 4 the rotation was fallow, barley, barley. The cereal crop was Olli barley. The crop sequence followed is shown in Table IV for the years 1958 to 1965 inclusive.

Fertilizers Applied:

Each field at the three locations was divided lengthwise into three strips of equal width. When producing barley, Plot No. 1 was fertilized with 50 lbs. ammonium phosphate, 11-48-0, per acre plus 50 lbs. ammonium nitrate

TABLE III - ROTATION SEQUENCE

GREEN AND FOX FARMS

	Field 1	Field 2	Field 3	Field 4	Field 5
1958	Legume	Barley & Legume	Barley	Barley	Barley
1959	Legume & Fallow	Legume	Barley & Legume	Fallow	Barley
1960	Barley	Legume & Fallow	Legume	Barley	Fallow
1961	Barley & Legume	Barley	Legume & Fallow	Barley	Barley
1962	*Legume & Fallow	Barley & Legume	Barley	Fallow	Barley
1963	Barley	Legume	Barley & Legume	Barley	Fallow
1964	Barley & Legume	Legume & Fallow	Legume	Barley	Barley
1965	Legume	Barley	Legume & Fallow	Fallow	Barley

* This field fallowed in error.

33.5-0-0, Plot No 2 was fertilized with 50 lbs. ammonium phosphate 11-48-0 alone, and Plot No. 3 received no fertilizer. The ammonium phosphate 11-48-0 on Plots 1 and 2 was increased to 100 lbs. when a field was producing legume for hay or seed. All fertilizers were applied in the spring with a fertilizer attachment on a farm grain drill. On the barley crops, the ammonium nitrate was applied as a separate operation prior to seeding while the ammonium phosphate was drilled in with the grain. Fertilizers were applied on the legume crops with the grain drill. Tables No. V and VI diagrammatically show the layout of the fertilized plots within each of the fields.

The corners of the fields at all three locations were marked by driving

TABLE IV - ROTATION SEQUENCE

THE WADE FARM

	Field 1	Field 2	Field 3	Field 4
1958	Barley & Legume	Barley	Barley	Barley
1959	Legume & Fallow	Barley & Legume	Fallow	Barley
1960	Barley	Legume & Fallow	Barley	Fallow
1961	Barley & Legume	Barley	Barley	Barley
1962	Legume & Fallow	Barley & Legume	Fallow	Barley
1963	Barley	Legume & Fallow	Barley	Fallow
1964	Barley & Legume	Barley	Barley	Barley
1965	Legume	Barley & Legume	Fallow	Barley

iron pipes into the ground. Wooden pegs were used to identify fertilizer plots within a field. These wooden pegs were replaced periodically by measuring from the iron pipes at the corners of a field.

Cultivation Methods:

Cultivation of each experimental plot was done by the farmers who made the decisions as to how and when cultivation should be done. Each farmer, however, was directed to seed all of his barley plots on the same day and also was assisted with the seeding to ensure that proper amounts of fertilizers were applied to each plot. In every spring, the cultivation on each field seeded to barley was the same. Each farmer handled the fall cultivation work exactly the same as he did on the rest of his farm.

TABLE V - LAYOUT OF FIELDS AND FERTILIZER PLOTS

GREEN AND FOX FARMS

Field 1			Field 2			Field 3			Field 4			Field 5		
Plots			Plots			Plots			Plots			Plots		
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
NP	P*	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck

TABLE VI - LAYOUT OF FIELDS AND FERTILIZER PLOTS

THE WADE FARM

Field 1			Field 2			Field 3			Field 4		
Plots			Plots			Plots			Plots		
1	2	3	1	2	3	1	2	3	1	2	3
NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck

Legend for Tables V and VI -

NP - 50 lbs./ac. 11-48-0, plus 50 lbs./ac. 35.5-0-0 on barley

100 lbs./ac. 11-48-0, plus 50 lbs./ac. 35.5-0-0 on legume

P* - 50 lbs./ac. 11-48-0 on barley

100 lbs./ac. 11-48-0 on legume

Ck - No Fertilizer

The farmers tilled the partial legume-fallow, and the regular summer fallow as they saw fit. All three farmers followed good cultural practices which meant that weeds were never a problem.

* Throughout the balance of the thesis P is used as the symbol for this treatment for the sake of simplicity. Note that a small amount of N is also present.

Harvesting Methods:

Grain yields were harvested by the square yard method with ten cuts equally placed throughout the length of each fertilized strip. The grain from each square yard cut was placed in a cotton bag, air dried, threshed, and the weight of the grain recorded.

In some years, the legume was utilized as hay and at other times left for seed production. Hay yields were taken spasmodically, but sufficiently often to work out an average hay yield. Ten square yard cuts were taken per fertilizer plot, and the green weight of the hay recorded. Six cuts per field were air dried to hay standards, weighed, and the water loss determined. The hay weight of the other cuts was calculated by assuming that they lost the same average water content as the ones dried and weighed.

Soil Sampling Analyses:

In the fall of 1965, soil samples at depths of 0 - 6, 6 - 12, and 12 - 24 inches were taken from each fertilizer treatment from each field at the three locations. The soil in each treatment of a field was sampled, to the 24 inch depth, at ten locations equally spaced throughout the length of the strip. The ten samples for each of the three depths were placed in three pails, the soil in each pail was mixed, and a composite sample taken for each depth of soil on the fertilizer treatment. These samples were analyzed to determine if any differences had arisen during the experiment as a result of the various treatments. The soil samples were air dried immediately after being taken, stored, oven dried, and ground to pass through a 2 mm mesh sieve.

Each soil sample was analyzed as follows, using methods currently in use in the Agricultural Soil and Feed Testing Laboratory, University of Alberta:

(1) pH Determination - A saturated paste was made by adding distilled

water to approximately 80 grams of soil in a paper cup. This was allowed to stand for approximately 30 minutes, at which time the paste was remixed, the glass electrodes of a Beckman pH meter inserted, and the pH read.

(2) Determination of soluble salts - The saturated paste from the pH determination was filtered through a Buckner funnel into a suction flask. The conductivity of this soil solution was determined by a Solu-Bridge conductivity meter.

(3) Total nitrogen determination - This was done by the Kjeldahl method to determine organic and ammoniacal nitrogen but not nitrates. Using the commercially prepared "Kel-pak" catalyst containing 9.9 grams of K_2SO_4, 0.08 grams of $CuSO_4$, and 0.41 grams of HgO, the soil was digested in 30 ml of concentrated H_2SO_4, and after cooling, about ½ gram of zinc was added and approximately 100 ml of sodium hydroxide. This mixture was distilled into boric acid and titrated with a standard H_2SO_4using a dye indicator to determine the end point.

(4) Available phosphorus was determined using .03N H_2SO_4- .03N NH_4F extractant. Five grams of crushed soil and ½ tsp. of carbon black were placed in a 50 ml Erlenmeyer flask. Twenty-five (25) ml of extracting solution were added and the flask was shaken for 2 minutes. This mixture was then filtered and a 10 ml aliquot taken. To this was added 10 ml of molybdate reagent and the intensity of the color was measured with a spectrophotometer.

(5) Available potassium determination - This was done with a flame photometer using 1.0 N ammonium acetate as the extracting solution. Five (5) grams of crushed soil were placed in a 50 ml flask and 25 ml

of extracting solution added. This was shaken for five minutes and filtered. Ten ml of 100 ppm lithium solution were added to a 10 ml aliquot of the filtrate, this was allowed to stand for 15 minutes, and the potassium concentration determined by a Baird flame photometer.

(6) Available nitrate determination - Five (5) grams of soil were placed in Erlenmeyer flasks to which was added 25 ml of nitrate extracting solution. After shaking for ten minutes, 1/8 tsp. of $Ca(OH)_2$ was added and shaken for five minutes. Then ½ tsp. of Mg CO_3 was added and shaken for two minutes. The solution was filtered and a 10 ml aliquot measured into a 50 ml beaker. This was evaporated to dryness on a hot plate at low heat; 2 ml of phenoldisulphonic acid were added to the residue, allowed to stand for ten minutes, and about 10 ml of distilled water were then added. This solution was transferred to a 50 ml volumetric flask and distilled water used to bring the contents to 50 ml. The color intensity was compared on a Coleman spectrophotometer at the 415 millimicron wave length.

(7) The particle size was determined on samples of each of the 0-6, 6-12, and 12-24 inch samples of soil from each location by the hydrometer method. The procedure as outlined by Bouyoucos (1961) consisted of soaking 50 grams of oven-dried soil in 100 cc of calgon solution for 15-20 hours. This mixture was then rinsed into a dispersing cup and mixed for two minutes by running the dispersing machine at 16,000 rpm. The solution was then rinsed into a soil sedimentation cylinder, made up to 1,000 ml, and stirred thoroughly. Immediately after stirring, about three drops of amyl alcohol were added to dissipate any froth and within 15 seconds the hydrometer

was placed into the soil suspension.. A reading was taken at 40 seconds after stirring ceased and the temperature and time noted. A further reading was taken exactly two hours after the first one. Both readings were corrected to 68^{o} Fahrenheit, which is the temperature at which the hydrometer is calibrated. The percentage of sand was obtained from the first reading, the clay from the second, and the silt from the difference between the two.

(8) The Statistical Analyses were done on the equipment of the Department of Computing Science, University of Alberta. A program for Analysis of Variance for Factorial Design developed by the School of Medicine, University of California, Los Angeles, was used. The data cards of the foregoing program instructed the computer to calculate and print out the variables, number of levels of each variable, the grand mean, the source of variation, the degrees of freedom, the sums of squares and their total, the mean squares, the cell numbers with their means, and the marginal means for each level of each variable. (See Appendix III for sample print out of Problem 01).

Analyses of variance were done on the barley yields at each location for every year (1958-1965 inclusive). These analyses compared the grain yields for the year of the various fields and, consequently, provided comparisons between the legume rotation and the non-legume one. The fields and fertilizer treatments were the variables involved.

An overall analysis of variance of the grain yields was done on five years out of the eight. It was not possible to use all data from the eight years, because it was necessary to have yields

from crops of consistent treatments, i.e. yields after legume-fallow, compared to ordinary fallow, or grain after grain at all locations. The three locations in this analysis were considered as replicates, the five years as No. 1 variable, the two rotations as No. 2 variable, and the three fertilizer treatments as No. 3 variable. These analyses gave an excellent comparison of the yield differences between the rotations and among the fertilizers and the years.

Analyses of variance were computed for total nitrogen, available phosphorus, available potassium, and available nitrate data, for each of the 0-6, 6-12, and 12-24 inch soil depths. These analyses were done to determine any soil nutrient differences that might have developed during the experiment due either to rotations or fertilizers or a combination thereof.

All means obtained by the analysis of variance for factorial design were compared for significance at the 5% level, and in a few cases the 1% level by using Duncan's New Multiple Range Test (Steel and Torrie, 1964). This test allowed for the determination of significant differences between any two treatment means. The method determined the significance of differences between rotations and among locations, and fertilizer treatments. Significant Studentized Ranges in relation to the number of means being compared were obtained from Steel and Torrie. The standard error was obtained by taking the square root of the following: $\frac{\text{error mean square}}{\text{reps}}$. The least significant studentized ranges were obtained for the number of means being compared by multiplying the

significant studentized ranges by the standard error. The LSSR for the number of means being compared was subtracted from the largest mean and all means which were smaller than the resulting answer were significantly different from the largest. This procedure was repeated with the second largest mean and so on. All statistics were calculated in the original units measured. The means, or differences were converted to common units such as bushels per acre or pounds available N per 6" acre slice, etc. Significant differences among means are shown by the letter system "a", "b", "c", as described by Steel and Torrie. (See Appendix II for these calculations on Problem 01).

Economic Studies:

It was not possible to do a proper economic study on the whole experiment because no cost records were kept other than the cost of the fertilizers and the forage seed involved. All spring cultivations were the same and it was considered that the costs of legume-fallow and ordinary fallow were about equal. The legume sod was more difficult and thus more costly to plow than the fallow land, but the legume-fallow was not tilled as often as the ordinary fallow. Thus the extra cost of plowing of the one appeared to offset the extra cost of cultivation on the other.

The economic returns from the rotations and fertilizers were compared in five ways:

(1) The BBF* rotation without fertilizer, the BBF plus P applied to the grain, and the BBF + NP applied to the grain, were compared.

(2) The LLBB** rotation without fertilizer, the LLBB + P and the LLBB + NP, when the fertilizers were applied to both hay and grain crops were

* BBF - barley, barley and fallow

** LLBB - legume, legume-fallow, barley and barley.

compared.

(3) This comparison was the same as (2) with the exception that the P and NP fertilizers were assumed to have been applied to the grain crops only. This was done because the fertilizers as applied did not give any yield increases on the hay.

(4) The BBF and the LLBB rotations were compared.

(5) A compilation or pooling of such data as the value of marginal products, and the marginal costs from the three locations was made in order to make more general conclusions regarding rotations and fertilizers for the area.

The total grain produced for the period was obtained for a rotation plus fertilizer treatment by adding the yields for a particular treatment as reported in Tables VII, VIII and IX, and then multiplying this answer by four for the Green and Fox Farms, and by five for the Wade Farm. (The Green and Fox plots covered 20 acres in five fields, and the Wade plot was 20 acres in four fields.) The total grain yields were reduced to bushels equivalent per acre per year. Hay yields were treated in a similar way. (See Appendix I)

The barley was valued at 93 cents per bushel. This was a moving average of the actual Wheat Board Prices* received at Wanham, which were as follows:

1959	-	$ .66
1960	-	.73
1961	-	.94
1962	-	.83
1963	-	.85
1964	-	.88
1965	-	1.00 estimated

* R. E. English - private communication

The 93 cent price was calculated by multiplying the 1965 price times three, adding on the '64, '63, '62, '61 prices and then dividing by seven. Hay was valued at $15.00 per ton with a harvest cost of $7.50 per ton. The cost of the ammonium nitrate (35.5-0-0) averaged $80.00 per ton, and thus the 50 lb. rate cost $2.00 per acre fertilized. The ammonium phosphate averaged $107.00 per ton, or $2.67 per acre fertilized at the 50 lb. rate. The final comparison in each table (XXX, XXXI, XXXII and XXXIII) was the value marginal product and marginal cost per acre per year for the treatment. The details of a calculation using the Green Farm as an example are given in Appendix I.

RESULTS AND DISCUSSION

The production of both barley and hay crops varied from good yields to crop failures. The Green and Fox Farms produced a crop each year of the experiment, but crops on the Wade Farm were not harvested for three of the eight years.

Barley and Hay Yields:

The grain and hay yields obtained from the Green, Fox, and Wade Farms are shown in Tables VII, VIII and IX. The information from Tables III and IV in abbreviated form were incorporated into the yield tables for ease of comparing rotation and fertilizer results. The barley yields varied from 0 to 72.9 bushels per acre. Visual observations indicated that NP gave higher yields than P or check. The yields of the two barley crops after legume-fallow were often higher, but not by significant amounts, than the two crops after ordinary fallow. The 1958 barley yield at all locations was smaller than any of the succeeding ones. The legume and fallow rotations and the fertilizers applied appeared to have a beneficial effect on the yields of barley. Growing conditions were also an important variable. The yields obtained with several plots in the 50 and 60 bushels per acre range, proved that the Grey Wooded soils in question can produce favourable yields. This agreed in principle with work done at Breton, and by Federal Research Stations in Alberta.

The hay yields varied very little either with respect to years or fertilizer treatments. The fertilizers gave no apparent yield increase on the hay land. The average yields of hay plots for those years in which hay was harvested were 1.13, 1.42, and 1.36 tons/ac. for the Green, Fox and Wade Farms respectively. The average for all hay harvested was 1.24 tons/ac., compared

TABLE VII - BUSHELS OF BARLEY AND TONS OF HAY PER ACRE

THE GREEN FARM

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
1958	Legume			B & L			Barley			Barley			Barley		
	*			23.3	19.3	11.4	22.2	17.8	12.3	26.6	15.1	12.7	20.0	13.5	7.7
1959	L & F			Legume			B & L			Fallow			Barley		
	1.2	1.5	1.5	1.2	0.9	1.2	29.8	31.1	26.2				27.9	31.5	26.8
1960	Barley			L & F			Legume			Barley			Fallow		
	49.8	46.5	48.2	*			*			55.7	62.6	27.2			
1961	B & L			Barley			L & F			Barley			Barley		
	36.1	30.2	27.4	56.3	57.9	44.4	*			31.3	23.1	28.5	53.5	44.4	38.1
1962	L & F			B & L			Barley			Fallow			Barley		
	*			39.2	29.0	26.9	56.5	45.7	38.4				39.4	26.8	23.6
1963	Barley			L & F			B & L			Barley			Fallow		
	39.2	32.4	32.0	*			23.0	23.1	17.9	31.0	29.8	30.3			
1964	B & L			Barley			L & F			Barley			Barley		
	31.0	28.1	16.5	39.7	34.6	27.4	*			30.4	10.2	22.1	31.7	18.5	18.2
1965	Legume			Barley			Barley			Fallow			Barley		
	*			37.4	41.0	34.9	49.8	49.5	62.2				37.7	29.4	27.1

Legend - Barley yields are in bushels per acre; hay in tons per acre

NP - Nitrogen & Phosphorus Fertilizers (See Table V re rates)

P - Phosphorus Fertilizer (See Table V re rates)

Ck - No Fertilizer

B & L - Barley & Legume

L & F - Legume and partial Fallow.

* - Hay not sampled.

TABLE VIII - BUSHELS OF BARLEY AND TONS OF HAY PER ACRE

THE FOX FARM

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
1958	Legume			B & L			Barley			Barley			Barley		
	*			13.0	10.0	7.5	19.3	13.3	8.4	20.1	13.3	7.7	12.7	9.9	7.0
1959	L & F			Legume			B & L			Fallow			Barley		
	1.5	1.4	1.2	0.9	0.5	0.5	30.8	25.5	26.4				32.2	23.7	21.5
1960	Barley			L & F			Legume			Barley			Fallow		
	38.4	36.5	28.1	1.6	1.3	1.4	0.8	0.8	0.9	44.6	33.0	36.2			
1961	B & L			Barley			L & F			Barley			Barley		
	42.9	31.3	27.8	40.4	37.3	34.2	2.6	2.9	3.0	42.4	31.6	29.2	52.8	47.2	52.7
1962	L & F			B & L			Barley			Fallow			Barley		
	*			44.0	32.6	25.2	72.9	66.2	57.3				30.4	17.1	15.2
1963	Barley			L & F			B & L			Barley			Fallow		
	27.5	36.0	31.6	*			38.3	26.0	32.1	32.8	21.8	21.2			
1964	B & L			Barley			Legume			Barley			Barley		
	27.4	30.6	25.9	55.7	39.7	36.4	*			30.1	20.7	21.9	39.2	40.3	34.9
1965	Legume			Barley			L & F			Fallow			Barley		
	*			33.9	27.6	25.0	*						14.7	8.4	6.4

Legend - Barley yields are in bushels per acre; hay in tons per acre

NP - Nitrogen & Phosporus fertilizers (See Table V re rates)

P - Phosphorus fertilizer (See Table V re rates)

Ck - No fertilizer

B & L - Barley & Legume

L & F - Legume and partial fallow

* - Hay not sampled

TABLE IX - BUSHELS OF BARLEY AND TONS OF HAY PER ACRE

THE WADE FARM

	Field 1			Field 2			Field 3			Field 4		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
1958	B & L			Barley			Barley			Barley		
	0	0	0	0	0	0	0	0	0	0	0	0
1959	L & F			B & L			Fallow			Barley		
	*			39.1	34.1	30.0				31.3	18.7	16.3
1960	Barley			L & F			Barley			Fallow		
	65.1	53.0	51.8	1.45	1.2	1.45	66.5	64.8	61.8			
1961	B & L			Barley			Barley			Barley		
	53.6	49.8	47.8	60.5	56.3	54.1	68.1	63.7	48.3	64.4	71.6	66.7
1962	L & F			B & L			Fallow			Barley		
	*			50.5	36.3	35.9				56.4	39.0	49.9
1963	Barley			L & F			Barley			Fallow		
	0	0	0	0	0	0	0	0	0	0	0	0
1964	B & L			Barley			Barley			Barley		
	23.9	18.0	13.2	19.4	25.3	23.2	18.3	15.1	21.5	16.3	19.6	12.2
1965	Legume			B & L			Fallow			Barley		
	0	0	0	0	0	0	0	0	0	0	0	0

Legend - Barley yields are in bushels per acre; hay in tons per acre

NP - Nitrogen and phosphorus fertilizers (See Table VI re rates)

P - Phosphorus fertilizer (See Table VI re rates)

Ck - No fertilizer

B & L - Barley & Legume

L & F - Legume & Fallow

0 - Where 0 appears in table, indicates the plots were not harvested.

* - Hay not sampled.

to an average of 1.5 tons/ac. for tame hay throughout Alberta.[1]

The grain and hay yield data in Tables X, XI, and XII compare the differences between the legume-barley rotation and the grain-fallow sequence. The yields for each field were obtained from the analysis of variance for each year at each location. For each field the figure shown is the mean of the three fertilizer treatments in that particular field. The yield figures are underscored by letters. Any two yields underscored by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range test. The letter "a" was used to indicate the significance of the highest yield in relation to others, the letter "b" for the second highest, and the letter "c" for the third highest, etc.

Study of Tables X, XI, and XII, indicate little difference in barley yield between the legume and the non-legume rotation. For instance, on the Fox Farm for the year 1960, the yields of barley after fallow and legume-fallow were 37.9 and 34.3 bus./ac. respectively, and were not significantly different. In 1961, barley after barley in both rotations were not significantly different, and again in 1964 the yields following each kind of fallow were not significantly different. Similar observations can be made on the Green and Wade yields. The bushels per acre per year were higher at each location for the fallow rotation, but the percentage of the area in barley on the barley-fallow rotation for the eight years was larger than on the legume-fallow rotation. While the barley yields in bushels per acre per year were almost equal for the two rotations, the legume rotation produced quantities of hay as well as the grain. These are summarized in Table XIII.

The five years selected to statistically compare the yields from

1 R. E. English - private communication

TABLE X - BARLEY YIELDS IN BUS./AC. BY FIELDS AND HAY IN TONS/AC.

THE GREEN FARM

	Field 1	Field 2	Field 3	Field 4	Field 5	Mean Year Yield
1958		18.0 a	17.4 ab	16.8 ab	14.3 b	16.7
1959			29.0 a		28.7 a	28.9
1960	48.2			59.0		53.5
1961	31.3 a	52.9		27.7 a	45.4	39.3
1962		31.7 a	46.9		29.9 a	36.2
1963	34.5 a		21.3	30.2 a		28.7
1964	25.2 a	33.9		20.9 a	22.8 a	25.7
1965		37.7	53.8		31.4	41.0

	By Legume Rotation	By Fallow Rotation
Total Grain produced - All fields, all years	1,927.2 bus.	1,308.4 bus.
Bushels equivalent per acre per year -	19.7 bus.	20.5 bus.
Total hay produced - All fields, all years	40.3 tons	0
Tons equivalent per acre per year -	.42 tons	0

Letters "a" and "b" are used to compare

significance for the year.

TABLE XI - BARLEY YIELDS IN BUS./AC. BY FIELDS AND HAY IN TONS/AC.

THE FOX FARM

	Field 1	Field 2	Field 3	Field 4	Field 5	Mean Year Yield
1958		10.2 b	13.7 a	13.7 a	9.9 b	11.8
1959			27.6 a		25.8 a	26.7
1960	34.3 a			37.9 a		36.1
1961	33.9 ab	37.3 ab		34.3 ab	50.9	39.1
1962		33.9	65.5		20.9	40.1
1963	31.7 ab		32.1 ab	25.2		29.7
1964	28.0 b	39.3 a		24.2 b	38.0 a	32.4
1965		28.8			9.8	19.3

	By Legume Rotation	By Fallow Rotation
Total grain produced - All fields, all years	1,665.2 bus.	1,162.4 bus.
Bushels equivalent per acre per year -	17.3 bus.	18.2 bus.
Total hay produced - All fields, all years	51.82 tons	0
Tons equivalent per acre per year -	.540 tons	0

Letters "a" and "b" are used to compare significance for the year.

TABLE XII - BARLEY YIELDS IN BUS./AC. BY FIELDS AND HAY IN TONS/AC.

THE WADE FARM

	Field 1	Field 2	Field 3	Field 4	Mean Year Yield
1958		Grain not harvested			
1959		34.4		22.1	28.3
1960	56.6		64.4		60.5
1961	50.4	57.0 b	60.0 b	67.5	58.7
1962		40.9		48.4	44.7
1963		Grain not harvested			
1964	18.4 a	22.6	18.3 a	16.1 a	18.8
1965		Grain not harvested			

	By Legume Rotation	By Fallow Rotation
Total grain produced - All fields, all years	1,401.5 bus.	1,484 bus.
Bushels equivalent per acre -	17.5 bus.	18.6 bus.
Total hay produced - All fields, all years	34 tons	0
Tons equivalent per acre per year -	.42 tons	0

Letters "a" and "b" are used to compare significance for the year.

TABLE XIII - BARLEY AND HAY PER ACRE PER YEAR

THE GREEN, FOX, AND WADE FARMS

	Legume Rotation		Fallow Rotation
	Barley	Hay	Barley
Green	19.7 bus.	.42 tons	20.5 bus.
Fox	17.3 bus.	.54 tons	18.2 bus.
Wade	17.5 bus.	.42 tons	18.6 bus.

the rotations and fertilizers were 1959, 1960, 1961, 1962, and 1964, because the barley on the Wade Farm was not threshed during the other years. The rotation data were matched for each location as shown in Table XIV. By so doing the three farms were replicates and the five years, the two rotations, and the three fertilizer treatments were variables. The mean yields for the legume rotation, as shown in Table XIV, were higher than the barley-fallow rotation in all years except 1960.

The five year means for the legume rotation and the barley rotation were 38.65 bus./ac. and 37.34 bus./ac. respectively. The difference of 1.31 bus./ac. in favour of the legume rotation was not significant. This agreed with the discussion earlier of Tables X, XI, and XII.

The mean grain yields of the legume and fallow rotations for the five selected years varied from 27.9 bus./ac. to 50.1 bus./ac. as shown in Table XV, and were significantly different even at the 1% level. The large variation amongst yearly barley yields indicated wide variations in growing conditions throughout the time of this experiment.

The differences for the three fertilizer treatments, for the five selected years, were large as shown in Table XVI. The grand mean for the NP

TABLE XIV - YIELDS OF BARLEY FOR THE ROTATIONS

BUSHELS PER ACRE

	Legume Rotation	Barley-Fallow
1959	Barley after Barley	Barley after Barley
	30.3	25.5
1960	Barley after legume fallow	Barley after ordinary fallow
	46.4	53.7
1961	Barley after legume fallow	Barley after ordinary fallow
	49.1	48.7
1962	Barley after Barley	Barley after Barley
	35.5	33.1
1964	Barley after legume fallow	Barley after Fallow
	32.0	25.7

TABLE XV - MEAN GRAIN YIELDS FOR SELECTED YEARS

FOR THE THREE FARMS

Year		Bus./Ac.
1959	-	27.9b
1960	-	50.1a
1961	-	48.9a
1962	-	34.1
1964	-	28.8b

Letters "a" and "b" indicate yield significance amongst years.

TABLE XVI - MEAN YIELDS FOR FERTILIZERS

FOR THE THREE FARMS, ALL FIELDS

	Bus./Ac.		Check
Years	NP	P	Check
1959	31.8	27.4	24.5
1960	53.3	49.4	47.4
1961	50.9	48.9	46.8
1962	43.3	30.1	29.4
1964	31.3	29.7	25.4
Grand Means	42.2	37.1	34.7

All barley yields are significantly different within years, and the grand means are significantly different.

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treatment was significantly higher at the 1% level than the mean for the P treatment and the Check. The P fertilizer treatment, for the five year period, was significantly higher than the Check at the 5% level. Yield increases for NP over Check, NP over P, and P over Check, were 7.5, 5.1, and 2.4 bus./ac. respectively, on the average for all farms, all rotations, and five of the eight years.

The interaction between rotations and fertilizers was not significant. It was noted, however, that the P fertilizer treatment gave slightly higher yields of grain when used in the legume rotation compared to the fallow one as shown in Table XVII.

Soil Analyses:

The following results were obtained from the soil analyses.

TABLE XVII - ROTATION AND FERTILIZER TREATMENT RELATIONSHIP

BARLEY - BUS./AC., ALL FIELDS

	NP	P	Check
Legume Rotation	43.0	38.4	34.6
Fallow Rotation	43.3	35.9	34.9
Grand Means	43.1	37.1	34.7

Mechanical Analysis:

The sand, silt, and clay, percentages as determined on the soils of the Green, Fox, and Wade Farms are shown in Table XVIII. The figures were obtained by averaging the results of duplicate samples. The silty clay loam of the Green Farm agreed with the profile description prepared by the Soil Surveyors (Page 23). The Fox Farm soil was largely clay and agreed with the profile description as described on Page 20. The Wade Farm soil, which is heavy clay, agreed with the profile description on Page 24.

Soil Reaction (pH):

The soil reaction (pH) results as determined on each plot at the three locations are shown in Table XIX. Neither the rotations or fertilizers appeared to have any effect on the pH readings of the soils. Most profiles had about the same pH to the 24-inch depth. The soils on the Green and Wade Farms were almost neutral, but the Fox Farm showed acidity almost to the tolerance point of cereals. An application of lime was not tried on the Fox Farm. The pH readings agreed with those reported by the soil surveyors.

Conductivity:

The conductivity results in mmhos per square cm are reported in Table XX. The rotations or fertilizers did not affect the conductivity of

the soils. It was noted that conductivity became larger as the depth increased indicating that salts may have leached downward. The sulfate salts in the 12-24 inch layer of the soil on the Green Farm were somewhat high.

TABLE XVIII - PERCENTAGES OF SAND, SILT AND CLAY

		% Sand 2.0 - .05 mm	% Silt .05 - .002 mm	% Clay below .002 mm
Green	0- 6"	11	51	39
	6-12"	14	39	47
	12-24"	13	37	49
Fox	0- 6"	8	38	54
	6-12"	2	27	71
	12-24"	1	21	78
Wade	0- 6"	4	29	67
	6-12"	2	17	80
	12-24"	1	19	80

Available Nitrate Nitrogen:

The available nitrate nitrogen obtained at the various soil levels for the fertilizer treatments at each location are shown in Table XXI. Visual inspection of this table reveals that available nitrogen decreased at each location with increased depth of profile. The levels of this nutrient for the whole area were somewhat higher than those reported at Breton (Toogood et al.). The available nitrogen grand mean for the 0-6 inch soil slice averaged 17 lbs./ac. compared to ranges of 4 to 20 lbs./ac. at Breton with an estimated

TABLE XIX - SOIL REACTION (pH)

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green															
0- 6"	6.8	7.0	7.3	7.3	7.2	7.2	7.1	7.4	7.2	7.4	7.5	7.6	7.1	7.3	7.4
6-12"	7.0	6.9	7.2	7.6	7.5	7.2	7.4	7.3	7.0	7.3	7.5	7.5	7.1	7.1	7.5
12-24"	6.8	7.0	7.0	7.4	7.2	7.4	7.4	7.5	7.5	7.5	7.5	7.8	7.4	7.3	7.2
Fox															
0- 6"	5.6	5.5	5.6	5.5	5.5	5.6	5.4	5.6	5.7	5.8	5.7	5.6	5.6	5.5	5.6
6-12"	4.7	4.7	4.7	4.7	4.8	4.7	4.8	4.9	5.1	5.3	5.0	4.8	4.8	4.9	5.0
12-24"	5.8	5.0	4.9	4.9	4.8	4.9	4.8	4.8	4.8	4.9	4.8	4.8	4.8	4.9	4.9
Wade															
0- 6"	6.3	6.2	6.9	6.5	6.4	6.6	6.5	6.3	6.4	6.3	6.5	6.8			
6-12"	6.0	6.0	6.8	6.5	6.8	6.2	5.8	5.9	6.1	5.7	6.5	5.9			
12-24"	6.6	7.1	6.8	7.0	6.8	7.0	7.0	6.8	6.0	6.2	6.3	6.1			

- 51 -

TABLE XX - CONDUCTIVITY - mmhos per square cm

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green															
0- 6"	.25	.20	.25	.40	.40	.30	.30	.30	.35	.50	.40	.50	.25	.35	.35
6-12"	.45	.80	.45	.40	.40	.50	.55	.55	.45	.55	.50	1.00*	.30	.45	.50
12-24"	1.5*	1.1*	2.0*	.70	1.05*	.80	.80	1.7*	1.4*	2.0*	.70	1.15*	.80	.55	1.10*
Fox															
0- 6"	.35	.30	.20	.25	.30	.25	.35	.40	.40	.40	.30	.40	.30	.35	.35
6-12"	.25	.40	.25	.35	.25	.30	.30	.25	.35	.30	.40	.45	.35	.40	.30
12-24"	.90	.75	.50	.75	.60	.80	.75	.65	.50	.45	.65	.70	.80	.70	.50
Wade															
0- 6"	.30	.30	.60	.35	.25	.30	.40	.50	.40	.45	.35	.35			
6-12"	.25	.35	.70	.30	.70	.50	.35	.35	.70	.25	.25	.20			
12-24"	.70	.65	.70	.50	.50	.50	.35	.35	.25	.85	.35	.40			

*Sulfate Salts

- 52 -

TABLE XXI - AVAILABLE NITRATE NITROGEN

lbs./ac. for 6" Soil Slice

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green	* Legume			* Barley			* Barley			* Fallow			* Barley		
0- 6"	5	4	5	3	5	3	5	3	7	39	22	17	1	4	2
6-12"	3	1	2	3	3	1	5	4	4	8	5	10	3	3	3
12-24"	1	1	4	4	2	0	2	1	1	8	9	5	1	7	0
Fox	* Legume			* Barley			* Legume Fallow			* Fallow			* Barley		
0- 6"	1	1	1	12	7	9	44	51	54	44	17	27	6	9	3
6-12"	3	1	1	3	1	5	3	5	5	3	7	7	2	4	2
12-24"	1	1	1	0	0	1	14	9	16	11	3	3	1	1	3
Wade	* Legume			* Barley			* Fallow			* Barley					
0- 6"	4	6	12	16	15	15	30	44	38	12	12	11			
6-12"	2	5	2	6	16	5	17	17	16	7	5	3			
12-24"	1	3	3	4	2	2	12	9	12	4	2	6			

* Crop or fallow during 1965.

Soils sampled October 1965.

mean of 11.5 lbs./ac. It was noted that fields in legume-fallow or summer fallow during 1965, when the soil samples were taken, had more available nitrogen than fields producing grain or legume. Summer fallow appeared to release nitrogen. Field No. 4 (Green), Fields 3 and 4 (Fox), and Field 3 (Wade) are examples where available nitrates were high because these fields were either in legume or ordinary fallow during 1965. (See Table XXI).

The results obtained from the statistical analysis on the available nitrogen for the three locations, the two rotations, and the three fertilizer treatments are shown in Table XXV. There were significant differences between locations. The Fox Farm had more available nitrogen than the Green Farm but not the Wade Farm, at the 0 - 6 inch level. At the 6 - 12 inch depth, the Wade Farm had more of this nutrient than either the Green or Fox Farms. The available nitrogen of the soils in the fallow rotations at the 0 - 6 inch level was higher than those in legume-fallow, but not significantly so. This can be explained by the fact that one-half the samples for the fallow rotations came from land fallowed during 1965, whereas a smaller portion came from legume-fallowed land in the case of the legume rotations. The fallow rotations at the 6 - 12 inch level had more available nitrogen than the legume rotations. The fact that the fallow rotation land was idle more of the time than the legume rotation may have allowed the available nitrogen to leach downward. The means of available nitrogen at the 12 - 24 inch level were about one-quarter to one-third of those of the 0 - 6 inch level, and were quite consistent for locations, rotations, or fertilizers.

Available Phosphorus:

The results obtained from the available phosphorus analysis for the

0 - 6 inch level, as reported in Table XXII, were rather high for the Green Farm, but somewhat low for the other two as compared to results obtained at Breton (Toogood et al.) and elsewhere. The low available phosphorus content of the soil at the Wade Farm did not appear to be the limiting nutrient growth factor because the 11-48-0 did not give a large yield response over the Check, but the nitrogen plus phosphorus did. (See Table IX)

The statistical analysis of available phosphorus obtained for the locations, rotations, and fertilizers, are reported in Table XXVI. There was a marked difference in available phosphorus content of the soils at the 0 - 6 inch, 6 - 12 inch, and 12 - 24 inch levels at the three locations. Very little appeared in the 12 - 24 inch depth at the Green Farm, but the other two farms had almost equal amounts at each level. The available phosphorus for the three locations were all significantly different from each other at the 0 - 6 inch level, and significant differences also occurred at the 6 - 12 inch and 12 - 24 inch levels. There were no significant differences between the rotations, but the barley-fallow rotations appeared to have larger amounts of available phosphorus than the legume-fallow ones. This appeared to be the case at Breton too. The fertilizer treatments did not affect the amounts of available phosphorus in the soils, but more seemed to accumulate in the soil where the phosphorus fertilizers were applied. Available phosphorus occurred down to the 24 inch depth even at the Wade Farm where amounts were low at all three soil levels.

Available Potassium:

The available potassium at all three locations was relatively high as reported in Table XXIII. These data showed that the available potassium in the soils was close to the same amount throughout the 24 inch depth of all

TABLE XXII - AVAILABLE PHOSPHORUS

lbs./ac. for 6" Soil Slice

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green	* Legume			* Barley			* Barley			* Fallow			* Barley		
0- 6"	57	63	44	79	76	47	79	60	88	73	69	54	54	79	54
6-12"	13	6	12	34	34	19	35	3	5	9	19	6	16	28	35
12-24"	6	19	6	13	3	3	13	3	6	6	9	6	6	9	24
Fox	* Legume			* Barley			* Legume Fallow			* Fallow			* Barley		
0- 6"	28	25	14	31	25	22	31	13	21	41	25	34	25	28	22
6-12"	28	32	28	25	28	31	28	28	28	25	28	31	28	31	32
12-24"	6	3	3	41	28	31	38	28	25	31	29	31	24	31	31
Wade	* Legume			* Barley			* Fallow			* Barley					
0- 6"	6	6	7	3	1	8	9	19	16	16	13	31			
6-12"	28	2	2	28	1	8	3	9	9	9	3	9			
12-24"	6	3	3	3	3	6	3	4	3	3	3	8			

* Crop or fallow during 1965

Soils sampled October 1965.

TABLE XXIII - AVAILABLE POTASSIUM

lbs./ac. for 6" Soil Slice

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green	* Legume			* Barley			* Barley			* Fallow			* Barley		
0- 6"	440	294	342	248	324	448	324	208	440	330	372	456	420	420	500
6-12"	224	342	262	332	252	378	312	408	388	384	480	388	388	400	396
12-24"	336	306	336	260	248	276	220	240	354	354	354	354	398	436	282
Fox	* Legume			* Barley			* Legume Fallow			* Fallow			* Barley		
0- 6"	600	640	566	600	558	602	640	602	604	640	600	600	516	522	602
6-12"	580	516	526	464	488	488	424	378	516	516	516	522	548	468	448
12-24"	384	522	496	522	528	588	566	594	598	588	600	506	508	512	504
Wade	* Legume			* Barley			* Fallow			* Barley					
0- 6"	524	596	522	440	588	576	640	640	602	596	600	566			
6-12"	516	500	522	522	392	454	520	468	452	460	516	452			
12-24"	484	374	522	324	372	436	500	436	468	440	498	566			

* Crop or fallow during 1965.

Soils sampled October 1965.

- 57 -

TABLE XXIV - PER CENT NITROGEN IN THE SOILS

Organic and Ammoniacal Nitrogen

	Field 1			Field 2			Field 3			Field 4			Field 5		
	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck	NP	P	Ck
Green	* Legume			* Barley			* Barley			* Fallow			* Barley		
0- 6"	.13	.13	.11	.12	.14	.11	.11	.10	.09	.11	.11	.10	.12	.11	.10
6-12"	.08	.09	.07	.07	.08	.07	.08	.07	.07	.07	.08	.07	.08	.07	.08
12-24"	.08	.07	.07	.05	.07	.06	.07	.05	.05	.10	.06	.07	.08	.07	.06
Fox	* Legume			* Barley			* Legume Fallow			* Fallow			* Barley		
0- 6"	.19	.20	.19	.20	.22	.29	.21	.22	.25	.23	.20	.19	.19	.17	.19
6-12"	.05	.08	.09	.09	.09	.09	.11	.11	.13	.11	.12	.11	.09	.09	.10
12-24"	.08	.07	.07	.08	.07	.08	.10	.10	.10	.11	.11	.09	.09	.06	.08
Wade	* Legume			* Barley			* Fallow			* Barley					
0- 6"	.22	.22	.23	.20	.17	.25	.21	.22	.22	.22	.20	.23			
6-12"	.07	.08	.12	.09	.09	.12	.16	.12	.12	.15	.15	.15			
12-24"	.08	.09	.08	.09	.10	.09	.11	.10	.09	.08	.10	.08			

* Crop or fallow during 1965.

Soils sampled October 1965.

- 58 -

TABLE XXV - AVAILABLE NITROGEN

Means in lbs./ac. for a 6" Soil Slice

	Locations			Rotations		Fertilizers		
	G	F	W	LF	F	NP	P	Ck
0- 6"	9	24	21	16	20	20	16	17
	a	a	ab	a	a	a	a	a
6-12"	5	4	7	4	7	5	5	5
	a	a				a	a	a
12-24"	3	5	5	3	5	5	4	4
	a	a	a	a	a	a	a	a

TABLE XXVI - AVAILABLE PHOSPHORUS

Means in lbs./ac. for a 6" Soil Slice

	Locations			Rotations		Fertilizers		
	G	F	W	LF	F	NP	P	Ck
0- 6"	67.1	27.1	10.7	32.4	36.0	37.4	34.8	32.2
				a	a	a	a	a
6-12"	20.8	29.1	8.9	20.8	18.4	22.6	18.4	17.8
	a	a		a	a	a	a	a
12-12"	8.3	31.0	5.0	14.5	15.4	16.0	13.3	15.4
	a		a	a	a	a	a	a

Legend - G - Green
F - Fox
W - Wade
LF - Legume Fallow
F - Fallow
NP, P, and Ck - See Tables V, VI and VII

Note - The letter indicating significance at 5% level is independent for Locations, Rotations and Fertilizers at each depth.

TABLE XXVII - AVAILABLE POTASSIUM

Means in lbs./ac. for a 6" Soil Slice

	Locations			Rotations		Fertilizers		
	G	F	W	LF	F	NP	P	Ck
0- 6"	372	592 a	572 a	484 a	532 a	488 a	496 a	544 a
6-12"	378	480 a	480 a	428 a	460 a	448 a	438 a	448 a
12-24"	316	558	450	440 a	432 a	428 a	428 a	454 a

TABLE XXVIII - PER CENT NITROGEN

Organic and Ammoniacal Nitrogen

Means in Per Cent of Nitrogen in a 6" Soil Slice

	Locations			Rotations		Fertilizers		
	G	F	W	LF	F	NP	P	Ck
0- 6"	.109 a	.207 a	.215 a	.181 a	.173 a	.177 a	.173 a	.181 a
6-12"	.075	.101	.117	.095 a	.100 a	.096 a	.095 a	.101 a
12-24"	.065	.089 a	.089 a	.083 a	.079 a	.086 a	.082 ab	.075 b

Legend - G - Green
F - Fox
W - Wade
LF - Legume Fallow
F - Fallow
NP, P, Ck - See Tables V, VI, and VII

Note - The letter indicating significance at 5% level is independent for Locations, Rotations and Fertilizers at each depth.

profiles. This was particularly true for the Wade and Fox Farms. The amounts of potassium in the soils of the Fox and Wade Farms were high by Alberta Soils and Feed Testing Laboratory standards, and were almost adequate in the soils of the Green Farm.

The amounts of potassium in the soils of the three farms were significantly different as reported in Table XXVII. The soil on the Green Farm was low in potassium as compared to the Fox and Wade Farms at all three levels studied. There were no significantly different amounts of available potassium as a result of the rotations, or amongst the three fertilizers applied.

Total Nitrogen:

The nitrogen levels of the soils at the three farms were quite close to one another, and the decrease with the depth of soil profile was consistent as shown in Table XXIV. The available nitrogen was somewhat higher on the fields in fallow during 1965 compared to the cropped ones. The total nitrogen appeared to be just as high in the cropped fields as the fallowed ones. While all fields had about the same amounts of nitrogen, more of it was available after either legume or ordinary fallow.

The statistical analysis produced few significant differences in per cent nitrogen in the soils as reported in Table XXVIII. No significant differences occurred at any depth between the rotations, or amongst the locations, or fertilizer treatments at the 0 - 6 inch level. However, the Wade Farm soil was higher in total nitrogen than either the Fox or Green Farm soils at the 6 - 12 inch level, and Wade's Farm soil was also higher than Green's at the 12 - 24 inch level. The Sweet Clover roots might have produced more organic matter at lower depths (12 - 24 inch) than those of the

Red Clover on the other two farms. The soils of the two fertilizer treatments, at the 12 - 24 inch depth, were not significantly different, but one of them, NP, was significantly higher in total nitrogen than the unfertilized soils. (See Table XXVIII).

Relationship of Crop Yields to Soil Analyses:

The nutrient levels of available nitrogen, phosphorus, and potassium in the soils of the Green, Fox and Wade Farms, were almost equal with some minor exceptions. The Green Farm soil was low in available nitrogen, at time of sampling, as compared to the Fox and Wade Farms. (See Table XXV). However, Table XIII shows about equal yields for all three farms. The N fertilizer treatment did not give large yield increases on the Green Farm. Thus it appeared that the small amounts of N in the Green Farm soil at time of sampling were not a critical growth factor over the period of this experiment. The Wade Farm soil was low in available phosphorus (Table XXVI), particularly in the first foot of the profile. The grain yields as recorded in Table XXIX did not indicate that the lack of available phosphorus was a limiting yield factor. The application of P to Wade's Farm soil increased the yields only slightly, whereas the application of N and P gave much larger yield increases.

The legume rotation appeared to have no effect on the available nitrogen, phosphorus, potassium, and total nitrogen content of the soils, or any effect on the grain yields as compared to the non-legume rotation.

The Dollar Returns:

The economic comparisons for the Green Farm are reported in Table XXX. See Page 64 and Appendix I for mathematics involved. The total physical product of the grain increased in each rotation with the application of the fertilizer treatments. It should be noted that the LLBB rotation pro-

TABLE XX1X - BARLEY YIELD SUMMARY

Comparing NP, P, and Ck

	1958	1959	1960	1961	1962	1963	1964	1965
Green								
NP	22.5	28.8	52.8	44.3	45.0	30.9	33.1	41.7
P	16.4	31.3	54.6	38.9	33.8	28.4	22.9	40.0
Ck	11.0	26.5	53.3	34.6	29.6	26.6	21.1	41.3
Fox								
NP	16.3	31.5	41.5	44.6	49	32.8	34.6	24.3
P	11.6	24.6	34.8	36.8	38.6	27.9	32.8	18.1
Ck	7.7	24	32.2	35.9	32.6	28.3	30	15.7
Wade								
NP	Not Harvested	34.4	65.8	61.7	53.4	Not Harvested	19.5	Not Harvested
P		26.4	58.9	60.3	37.7		19.5	
Ck		23.2	56.8	54.2	42.9		17.5	

duced 0.11 bus./ac. more barley than the BBF. The P fertilizer treatment gave a good economic return on the BBF rotation. The investment in the N fertilizer treatment when added to BBF+P returned 240%. This study suggests that Green should add both nitrogen and phosphorus if he elects to follow a barley, barley, fallow rotation. The addition of P and NP to both the grain and hay land in the rotation LLBB did not pay for the fertilizers applied.

When the P fertilizer treatment was applied to the grain only in the LLBB rotation, it returned 126%. The return was 59% for the N fertilizer treatment when it was added to LLBB+P.

This economic analysis suggested that had Mr. Green used the LLBB

TABLE XXX - A COMPARISON OF THE MARGINAL RETURNS FROM THE ROTATIONS AND FERTILIZER TREATMENTS

THE GREEN FARM

R & F	T P P Barley Bus./Ac./Yr.	T P P Hay Tons/Ac./Yr.	M P Barley Bus./Ac./Yr.	M P Hay Tons/Ac./Yr.	V M P Dollars Ac./Yr.	M C Dollars Ac./Yr.	Per Cent Return on Investment
BBF	16.39						
			2.67		2.48	1.84	35
BBF+P	19.06						
			5.02		4.66	1.37	240
BBF+NP	24.08						
BBF	16.39						
			.11	.42	6.40	4.31	48
LLBB	16.50	.42					
			3.76		3.50	3.78	
LLBB+P	20.26	.42					
			2.01		1.87	2.00	
LLBB+NP	22.27	.42					
LLBB	16.50	.42					
			3.76		3.50	1.55	126
* LLBB+P	20.26	.42					
			2.01		1.87	1.17	59
*LLBB+NP	22.27	.42					
BBF	16.39						
			5.88	.42	11.77	7.03	67
*LLBB+NP	22.27	.42					

* See Page 68 for Table Legend.

- 64 -

rotation and applied 50 lbs. of 11-48-0 plus 50 lbs. of 33.5-0-0 per acre to the land in grain in this rotation, but not to the hay land, he would have made $4.74 (11.77 - 7.03) per acre per year more than the returns from the BBF sequence. On a 300 acre farm his extra yearly profit would have been $1,422.00.

The economic returns for the Fox Farm are reported in Table XXXI. The BBF rotation gave an economical return from the addition of NP, but not with P alone. The Fox Brothers should add both nitrogen and phosphorus to their grain crops if they plan to follow the BBF sequence. The LLBB rotation returned 52% when compared with BBF. The addition of P treatment to the grain and hay land was not profitable, however, the N treatment added to LLBB+P was profitable. The LLBB+NP, when the fertilizers were applied to both grain and hay land, was not profitable compared to LLBB. The study suggests that the Fox Brothers should have used the LLBB plus the NP fertilizer treatments applied to the grain crops in the rotation but not the hay. Had this been done on the 300 acre farm the extra yearly profit would have been (12.13 - 7.93) x 300 = $1,260.00.

The returns from the Wade Farm as reported in Table XXXII were much reduced because of the three crop failures involved. Mr. Wade's yields were the highest per acre per year in spite of the three failures. The Marginal Returns would have been good and no doubt have shown a profit if only the five crop years were considered. The P treatment when applied to BBF did not return a profit. The N treatment when added to BBF+P was profitable, but the combination of NP treatments when added to BBF was just profitable. The addition of the P treatment to both hay and grain land in LLBB did not return a profit, but the addition of N to LLBB+P was profitable. The combination of the NP treatments on LLBB returned no profit. When only the grain in LLBB was

TABLE XXXI - A COMPARISON OF THE MARGINAL RETURNS FROM THE ROTATIONS AND FERTILIZER TREATMENTS

THE FOX FARM

R & F	T P P Barley Bus./Ac.Yr.	T P P Hay Tons/Ac./Yr.	M P Barley Bus./Ac./Yr.	M P Hay Tons/Ac./Yr.	V M P Dollars Ac./Yr.	M C Dollars Ac./Yr.	Per Cent Return on Investment
BBF	15.87						
			.82		0.76	1.84	
BBF+P	16.69						
			5.30		4.93	1.37	262
BBF+NP	21.99						
BBF	15.87						
			-.63	.54	7.52	5.21	52
LLBB	15.24	.54					
			1.95		1.81	3.78	
LLBB+P	17.19	.54					
			3.01		2.80	2.00	40
LLBB+NP	20.20	.54					
* LLBB	15.24	.54					
			1.95		1.81	1.55	17
* LLBB+P	17.19	.54					
			3.01		2.80	1.17	139
LLBB+NP	20.20	.54					
BBF	15.87						
			4.33	.54	12.13	7.93	52
*LLBB+NP	20.20	.54					

* See Page 68 for Table Legend.

TABLE XXXII - A COMPARISON OF THE MARGINAL RETURNS FROM THE ROTATIONS AND FERTILIZER TREATMENTS

THE WADE FARM

R & F	T P P Barley Bus./Ac.Yr.	T P P Hay Tons/Ac./Yr.	M P Barley Bus./Ac./Yr.	M P Hay Tons/Ac./Yr.	V M P Dollars Ac./Yr.	M C Dollars Ac./Yr.	Per Cent Return on Investment
BBF	21.65						
			1.20		1.12	1.84	
BBF+P	22.85						
			2.25		2.09	1.23	70
BBF+NP	25.10						
BBF	21.65						
			-1.65	.43	4.92	3.97	24
LLBB	20.00	.43					
			1.31		1.22	3.50	
LLBB+P	21.31	.43					
			3.07		2.86	2.00	43
LLBB+NP	24.38	.43					
LLBB	20.00	.43					
			1.31		1.22	1.84	
* LLBB+P	21.31	.43					
			3.07		2.86	1.23	132
*LLBB+NP	24.38	.43					
* BBF	21.65						
			2.73	.43	9.00	7.04	28
LLGG+NP	24.38	.43					

* See Page 68 for Table Legend.

- 67 -

Legend for Tables XXX, XXXI and XXXII

R & F - Rotation and Fertilizer Treatment

BBF - Barley - Barley - Fallow Rotation

LLBB - Legume - Legume - Barley - Barley Rotation

TPP - Total Physical Product 1958-1965

MP - Marginal Product

VMP - Value Marginal Product

MC - Marginal Cost

P - Fertilizer Treatment 11-48-0 at 50 lbs./ac. on barley; amount doubled on hay.

NP - Fertilizer Treatment 11-48-0 at 50 lbs./ac., plus 33.5-0-0 at 50 lbs./ac. on barley; the amount of 11-48-0 was doubled on hay.

* - Fertilizers on Barley Crops only.

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fertilized, the P treatment was not profitable, but the addition of N treatment to LLBB+P was profitable. The combination of NP treatments to the grain only in LLBB returned a profit. The crop sequence LLBB+NP returned (9.00 - 7.04) = $1.96 more per acre annually than BBF. On a 300 acre farm this would amount to $588.00.

The totals, on a per acre per year basis, of the value of marginal products and the marginal costs for the three farms are reported in Table XXXIII. The pooled economic information of the three farms indicated the following:

(1) The addition of P to the BBF did not return a profit. The addition of N to BBF+P returned 194%. The combination of N and P treatments to BBF returned a profit.

TABLE XXXIII - POOLED DATA COMPARING VALUE MARGINAL PRODUCT AND MARGINAL COST FOR THE GREEN, FOX AND WADE FARMS

Rotations	V M P Dollars /Ac./Yr. For 3 Farms	M C Dollars /Ac./Yr. For 3 Farms	Per Cent Return on Investment
BBF			
	4.36**	5.52	
BBF+P			
	11.68	3.97	194
BBF+NP			
BBF			
	18.84	13.49	39
LLBB			
	6.53	11.06	
LLBB+P			
	7.53	6.00	25
LLBB+NP			
LLBB			
	6.53	4.94	32
*LLBB+P			
	7.53	3.57	110
*LLBB+NP			
BBF			
	32.90	22.00	49
*LLBB+NP			

Legend: BBF, etc. - See Page 68 for rotation legends.

* - Fertilizer on grain crops only

** - Figure obtained by adding the V M P between BBF and BBF+P from each of Tables XXX, XXXI and XXXII.

(2) The difference in per cent return between BBF and LLBB was 39 per cent.

(3) It was not profitable to use LLBB+P when the fertilizer was applied to the hay and grain lands. The addition of N to LLBB+P on both hay and grain lands returned 25 per cent. The combination of N and P treatments on both hay and barley land in LLBB was unprofitable.

(4) The P treatment on the grain only in LLBB returned 32 per cent, and the N when added to LLBB+P returned 110 per cent. The combination of both N and P fertilizer treatments applied to the grain only were profitable.

(5) The pooled economic information of the three farms comparing BBF with LLBB+NP on the grain only gave a 49 per cent return. Individually, the percentage returns were 67, 52, and 28, for Green, Fox, and Wade, respectively.

The pooled economic information of the three farms comparing BBF and LLBB+NP (See Table XXXIII) shows the total Value Marginal Product as $32.90, and the total Marginal Cost as $22.00, both on a per acre per year basis, when the fertilizer treatments were on the grain only in both rotations. The averages were $10.96 (VMP) and $7.33 (MC) respectively. This economic study suggested that had farmers of that area used LLBB+NP for the years 1958-1965 inclusive, they would have received $3.63 more profit per acre per year. On a 300 acre farm, this would have amounted to $1,089.00 extra profit per year.

SUMMARY AND CONCLUSIONS

The experimental work and the economic study completed for this thesis may be summarized as follows:

(1) Grey Wooded soils of the Wanham and Silver Valley areas can be made to produce high yields of grain.

(2) The barley yields varied from 0 to 67.5 bus./ac. on some fields.

(3) The fertilizers applied gave significant grain yield increases on both non-legume and on legume rotations. No increases from the fertilizers were obtained on the hay yields.

(4) During some years, the barley yields after legume-fallow were significantly higher than after fallow. The mean barley yield from the legume rotation was higher than the mean barley yield of the non-legume rotation. The difference was not significant.

(5) Neither the rotations nor the fertilizers applied changed the available nitrogen, available phosphorus, available potassium, or total nitrogen content of the soils.

(6) The economic study showed that the LLBB gave a 39 per cent return compared to the BBF rotation. The N plus P fertilizer treatments when applied on the BBF rotation were profitable. The N plus P treatments did not return a profit on LLBB when both hay and grain plots were fertilized. The LLBB rotation compared to the BBF one, with the N plus P treatments applied to the grain crops only, gave a 49 per cent return when the data from the three farms were pooled.

The literature review, the experimental work, the economic study, and the soil test results would suggest that farmers in the Wanham and Silver Valley areas should have used a rotation comparable to LLBB, but not

necessarily as rigid, and should have applied 50 lbs. of 33.5-0-0 plus 50 lbs. of 11-48-0 per acre to the grain crops during the years 1958-1965 inclusive. The higher marginal value of the nitrogen, as compared to the phosphorus, suggests that it would be more important to satisfy first the nitrogen deficiencies in the soils, and then to supplement with phosphorus. It is possible that fertilizers at the above rates on the grain crops would give a satisfactory return in the future on a 50% legume to grain rotation. An application of nitrogen alone as a treatment would have improved the design of the experiment and helped to clarify the relative value of nitrogen and phosphorus. More study is needed as to optimum rates.

REFERENCES

Allaway, W. H. 1957. Cropping systems and soil. In Soil, the 1957 Yearbook of Agriculture. U.S. Dept. of Agr., Washington, D.C.

Bouyoucos, G. J. 1961. Improved hydrometer method for particle size analyses. Agron. J. 54: 464-465.

Brown, A.D., F. A. Wyatt, and J. D. Newton. 1942. Effects of cultivation and cropping on the chemical composition of some Western Canada prairie soils. Sci. Agr. 23: 229-232.

Carder, A.C., and A. A. Hanson. 1951. Sweet clover and the Grey Wooded soils of the Peace River region. Sci. Agr. 31: 325-344.

Carlson, C.W., D. L. Grunes, H. R. Haise, and J. Alessi. 1963. Effect of alfalfa on the nitrogen and phosphorus requirements of crops. Soil Sci. Soc. Amer. Proc. 27: 319-323.

Drover, D. P. 1956. The influence of various rotations on coarse-textured soils at Chapman and Wongan Hills research stations. Australian J. Soil Sci. 7: 151-155.

Dubetz, S. 1954. The fertility balance in a ten year sugar beet rotation after forty-two years of cropping. Proc. Am. Soc. Sugar Beet Technol. 8: 81-85.

Fletcher, P. W. and R. B. Livingston. 1949. Structure improvement following legume growth on unfertilized subsoil. Soil Sci. Soc. Amer. Proc. 14: 347-350.

Gosdin, G. W., M. Stelly, and W. E. Adams. 1949. The organic matter and nitrogen content and carbon-nitrogen ratio of Cecil soil as influenced by differing cropping systems on classes II, III, and IV land. Soil Sci. Soc. Amer. Proc. 14: 203-208.

Heady, E. O. 1957. Economics of cropping systems. In Soil, the 1957 Yearbook of Agriculture. U.S. Dept. Agric., Washington, D.C.

Heady, E. O., and H. R. Jensen. 1951. The economics of crop rotations and land use. Agr. Expt. Sta., Iowa State College. Res. Bull. 383.

Hill, K. W. 1954. Wheat yields and soil fertility on the Canadian prairies after a half century of farming. Soil Sci. Soc. Amer. Proc. 18: 182-184.

Lehane, J. J., F. G. Warder, and W. J. Staple. 1964. Decline of wheat yields and depletion of some nutrients on a loam soil during a 36-year period. Can. J. Soil Sci. 44: 50-55.

Newton, J. D., F. A. Wyatt, and A. L. Brown. 1945. Effects of cultivation and cropping on the chemical composition of some Western Canada prairie province soils. Part III, Sci. Agr. 25: 718-737.

Odynsky, Wm., and J. D. Newton. 1950. Soil survey of the Rycroft and Watino sheets. Report No. 15, Alberta Soil Survey, Edmonton.

Poyser, E. A., R. A. Hedlin, and A. O. Ridley. 1957. The effect of farm and green manures on the fertility of black earth- meadow clay soils. Can. J. Soil Sci., 37: 48-56.

Progress Report. 1953-57. Expt. Farm Service, Can. Dept. Agr., Brandon.

Progress Report. 1949-1958. Expt. Farm Service, Can. Dept. Agr., Fort Vermilion.

Progress Report. 1937-1947. Expt. Farm Service, Can. Dept. Agr., Scott.

Research Report. 1958-1961. Expt. Farm, Can. Dept. Agr., Beaverlodge.

Research Report. 1958-1961. Expt. Farm, Can. Dept. Agr., Brandon.

Russell, E. J. 1917. The Book of the Rothamsted Experiments. E. P. Dutton and Company, New York.

Russell, E. W. 1961. Soil conditions and plant growth. ninth edition. Farrold and Sons Ltd., Norwich, England.

Siemens, L. B. 1963. Cropping systems. Study Report, Univ. Manitoba.

Snider, H. J. 1950. Soil building with legumes. Agr. Expt. Sta., Univ. of Illinois. Bull. 539.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York.

Toogood, J. A., and D. L. Lynch. 1959. Effect of cropping systems and fertilizers on mean weight diameter of aggregates of Breton plot soils. Can. J. Soil Sci. 39: 151-156.

Toogood, J. A., C. F. Bentley, G. R. Webster, and A. W. Moore. 1962. Grey Wooded soils and their management. Univ. of Alberta. Bull. 21, sixth edition.

University of California. 1961. Analysis of variance for factorial design, Program No. 225046, Program name BMDo2V. School of Medicine, Univ. of Calif., Los Angeles, Calif. (Copy of program in Dept. of Comp. Sci., Univ. of Alberta, Edmonton.)

Walker, D. R., and C. F. Bentley. 1961. Sulphur fractions of legumes as indicators of sulphur deficiency. Can. J. Soil Sci. 41: (2) 164-168.

APPENDIX I

The following example explains how the figures in Table XXX were calculated:

(1) Table III contains the fact that the BBF rotation was in Fields 4 and 5, and that LLBB was in Fields 1, 2 and 3. To get the TPP (Total Physical Product) figure $16.39 (Table XXX) for the barley in Bus./Ac./Yr., add all the grain yields under Ck in Fields 4 and 5 (Table VII), and multiply by 4 (acres per field) then divide by 64, which is 2 fields x 4 acres each x 8 years. Similar calculations were made for the other rotations, etc.

(2) The hay yield for each farm was determined by averaging all the hay crops grown. This was 1.13 tons per acre. Nine hay crops were produced for a total tonnage of 40.68 (1.13 x 4 acre/field x 9 crops). This was on 96 acres (8 yrs. x 3 fields x 4 acres). The tons/Ac./Yr. was 40.68 ÷ 96 = 0.42 tons.

(3) The MP (Marginal Product) was obtained by subtracting the TPP for the two rotations being compared. An example would be (BBF+P) 19.06 - 16.39 (BBF) = 2.67. (Top of Table XXX).

(4) The VMP (Value Marginal Product) was obtained by multiplying the bushels of grain by $ .93 and the tons of hay by $15.00, and adding the two together where this applied.

Examples:- 2.67 x .93 = 2.48 or between BBF and LLBB was

(.11 x .93) + (.42 x 15.00) = $6.40.

(5) The MC (Marginal Cost) is the extra cost between the rotations being compared. For example:- Comparing BBF and BBF+P, the P was applied to 11 grain crops on a total of 44 acres (Table VII) at a cost of

$2.67 per acre. Total cost of P/Ac./Yr. was 2.67 x 44 ÷ 64 (2 fields x 4 acres x 8 years) = $1.84. Similar methods were used where hay was involved with the harvesting costs at $7.50 per ton.

(6) The per cent return was done as follows:

$$\frac{VMP - MC}{MC} \times 100 = \%$$

(7) The Pooled Data (Table XXXIII) were obtained by the addition of comparable figures from Tables XXX, XXXI, and XXXII. For example: the figure 4.36 (Table XXXIII) used to compare BBF with BBF+P was obtained by adding 2.48 (VMP - Table XXX), 0.76 (VMP - Table XXXI), and 1.12 (VMP - Table XXXII) together.

The per cent return was computed as in 6 above.

APPENDIX II

Problem No. 1 - Green 1958 (See Appendix III)

The error has 108 degrees of freedom, and is obtained by adding the degrees of freedom opposite source of variation 3, 13, 23 and residual. The sum of squares for error is obtained by adding the sum of squares opposite 3, 13, 23 and residual. It is 79,343. The mean square for error is 79343 ÷ 108 = 761.

The standard error of means for fields is -

$$\sqrt{\frac{761}{\text{reps}}} = \sqrt{\frac{761}{30 \text{ (3 fertilizers x 10 cuts)}}} = 5.04$$

The standard error of means for fertilizers is -

$$\sqrt{\frac{761}{\text{reps}}} = \sqrt{\frac{761}{40 \text{ (4 fields x 10 cuts)}}} = 4.39$$

* Significant Studentized Ranges	2.77	2.92	3.02
Number of means	2	3	4
Least Significant Studentized Range			
for fields (2.77 x 5.04 etc.)	13.96	14.72	15.22
for fertilizers (2.77 x 4.39 etc.)	12.16	12.82	

Comparison of Fields -

Fields	4	3	2	1
Means for fields	64.5	75.7	78.5	81.1

Therefore 81.1 - 15.22 (4 means) = 65.88. Thus each other mean that is smaller than 65.88 is significantly different than the mean for Field No. 1. Therefore means 1, 2, & 3 are not significantly different, but No. 1 is significantly larger than for No. 4.

(See comparison of fertilizers on next page.)

* Steel and Torrie

Comparison of fertilizers -

Number of means	3	2	1
Means for fertilizers	49.6	74.0	101.3
LSSR (4.39 x .277 etc.)	12.16	12.82	

Therefore 101.3 - 12.82 = 88.48, and each mean that is smaller than 88.48 is significantly different from No. 1.

Thus No. 1 is greater than 2 and 3, and 74.0 - 12.16 = 51.84, therefore No. 2 is greater than No. 3.

Thus all (1, 2, and 3) means are significantly different.

APPENDIX III

BMD02V - ANALYSIS OF VARIANCE FOR FACTORIAL DESIGN - VERSION OF MAY
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM NO. 01

NUMBER OF VARIABLES 3
NUMBER OF REPLICATES 1

VARIABLE	NO. OF LEVELS
1	4
2	3
3	10

GRAND MEAN 74.96667

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARES
1	3	0.47588662E 04	0.15862887E 04
2	2	0.53519804E 05	0.26759902E 05
3	9	0.47270329E 04	0.52522588E 03
1 2	6	0.28559917E 04	0.47599861E 03
1 3	27	0.27789963E 05	0.10292579E 04
2 3	18	0.80185214E 04	0.44547341E 03
RESIDUAL	54	0.38807649E 05	0.71866016E 03
TOTAL	119	0.14047783E 06	

APPENDIX III

Problem No. 01 - Green 1958

Variable No. 1 was the four Green fields 2, 3, 4, & 5, but were renumbered 1, 2, 3, & 4 respectively for computer purposes. Fields 2 & 3 (computer 1 & 2) were in the LLBB rotation and fields 4 & 5 (computer 3 & 4) were in the BBF rotations.

Variable No. 2 was the fertilizers and are as follows:

1 - N+P fertilizers

2 - P fertilizers

3 - No fertilizer

Variable No. 3 was the ten cuts harvested per the treatment. All figures are in gms. per square yard until converted to bus./ac. for this thesis.

The means yields for each field and each fertilizer are printed out under the heading "Marginal Means".

Variable No. 1 - Category 1, 2, 3 & 4 are the fields.

Variable No. 2 - Category 1, 2, & 3, are the fertilizers.

Variable No. 3 - Category 1 to 10 inclusive are the cuts.

The cell number III is field 1, fertilizer 1, and cut 1.

The Source of Variation, Degrees of Freedom, Sums of Squares, and Mean Squares are self explanatory. See Appendix II for calculations.

PROBLEM NO. 01

CELL NUMBERS	MEANS
1 1 1	94.00000
1 1 2	125.00000
1 1 3	79.00000
1 1 4	76.00000
1 1 5	72.00000
1 1 6	70.00000
1 1 7	190.00000
1 1 8	80.00000
1 1 9	142.00000
1 1 10	122.00000
1 2 1	96.00000
1 2 2	75.00000
1 2 3	114.00000
1 2 4	93.00000
1 2 5	68.00000
1 2 6	79.00000
1 2 7	92.00000
1 2 8	92.00000
1 2 9	89.00000
1 2 10	72.00000
1 3 1	34.00000
1 3 2	39.00000
1 3 3	50.00000
1 3 4	62.00000
1 3 5	42.00000
1 3 6	44.00000
1 3 7	52.00000
1 3 8	56.00000
1 3 9	68.00000
1 3 10	65.00000
2 1 1	83.00000
2 1 2	72.00000
2 1 3	99.00000
2 1 4	96.00000
2 1 5	97.00000
2 1 6	101.00000
2 1 7	66.00000
2 1 8	73.00000
2 1 9	144.00000
2 1 10	170.00000
2 2 1	112.00000
2 2 2	76.00000
2 2 3	123.00000
2 2 4	95.00000
2 2 5	60.00000
2 2 6	44.00000
2 2 7	76.00000
2 2 8	40.00000
2 2 9	58.00000
2 2 10	119.00000
2 3 1	64.00000
2 3 2	49.00000
2 3 3	94.00000
2 3 4	90.00000
2 3 5	68.00000
2 3 6	31.00000
2 3 7	18.00000
2 3 8	24.00000

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3	1	1	84.00000
3	1	2	118.00000
3	1	3	120.00000
3	1	4	80.00000
3	1	5	64.00000
3	1	6	38.00000
3	1	7	107.00000
3	1	8	156.00000
3	1	9	149.00000
3	1	10	104.00000
3	2	1	58.00000
3	2	2	54.00000
3	2	3	60.00000
3	2	4	71.00000
3	2	5	79.00000
3	2	6	68.00000
3	2	7	67.00000
3	2	8	60.00000
3	2	9	58.00000
3	2	10	103.00000
3	3	1	44.00000
3	3	2	94.00000
3	3	3	40.00000
3	3	4	44.00000
3	3	5	36.00000
3	3	6	67.00000
3	3	7	64.00000
3	3	8	72.00000
3	3	9	37.00000
3	3	10	75.00000
4	1	1	103.00000
4	1	2	87.00000
4	1	3	76.00000
4	1	4	115.00000
4	1	5	142.00000
4	1	6	174.00000
4	1	7	97.00000
4	1	8	73.00000
4	1	9	60.00000
4	1	10	55.00000
4	2	1	11.00000
4	2	2	70.00000
4	2	3	80.00000
4	2	4	90.00000
4	2	5	64.00000
4	2	6	54.00000
4	2	7	69.00000
4	2	8	72.00000
4	2	9	41.00000
4	2	10	56.00000
4	3	1	79.00000
4	3	2	42.00000
4	3	3	38.00000
4	3	4	34.00000
4	3	5	24.00000
4	3	6	32.00000
4	3	7	22.00000
4	3	8	26.00000
4	3	9	2.00000
4	3	10	49.00000

M A R G I N A L M E A N S

VARIABLES	CATEGORIES	M E A N S

R. L. CRAIN LIMITED

University of Alberta
Department of Computing Science

1	1	81.06666
	2	78.53333
	3	75.70000
	4	64.56667
2	1	101.32500
	2	73.95000
	3	49.62500
3	1	71.83333
	2	75.08333
	3	81.08333
	4	78.83333
	5	68.00000
	6	66.83333
	7	76.66667
	8	68.66667
	9	74.50000
	10	88.16667

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